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LUMINOUS TUBE LIGHTING

INCLUDING HIGH VOLTAGE FLUORESCENT LIGHTING

Dealing with the principles of the Luminous Tube,
with a Summary of the Materials and Equipment involved,
and Technical Data concerning Discharge-Tube
Light Sources

By

HENRY A. MILLER, A.M.I.E.E.

With one hundred and four Illustrations

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PREFACE

This book is designed to explain the underlying principles of the luminous tube, summarise the materials and equipment involved, and describe each of the discharge tube light sources.

Some years ago, luminous tube technique was regarded as something of a fetish and the whole business was bristling with so-called trade secrets. Thus, the electrical engineer wishing to know something of this subject was hampered at the start.

Gradually, as the tube was becoming a recognised light source, the technical barriers began to break down. Then, when discharge tube practice at last became an integral part of the electrical industry, and shortly after the advent of the fluorescent tube, war broke out with its deleterious effect on lighting generally. This book has been planned to enable electrical engineers and contractors to pick up the threads.

Considerable attention has been paid throughout to the low-pressure tube which will probably play a large part in the decorative lighting of the future.

Much of the material in the chapter entitled "Data and Tests" has been obtained as a result of experimental work carried out in the luminous tube factories of the Miller Sign Company, Limited. To other firms and individuals who have helped in many ways to make the book possible, grateful acknowledgments are made elsewhere.

NOTE ON THE SECOND EDITION

In addition to the standard fluorescent lamps, another fluorescent light source is rapidly gaining favour—the so-called "cold-cathode" tubing, which is similar in principle to the luminous tubing used in Neon Signs.

In view of the potential scope of cold cathode fluorescent lighting, the first edition of this book has been enlarged to include more details of this new light source.

In this connection, acknowledgments are made to the publishers of the *Electrical Review* and the *Electrical Times* for their permission to reproduce material and diagrams from my recent articles.

H. A. Miller, A.M.I.E.E.

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Chapter 1

INTRODUCTION

THE brilliantly glowing neon tube is no longer regarded as an innovation in the field of advertising, and its attractive appearance coupled with a remarkable power of penetration under conditions of low visibility are indisputable. It is actually the neon sign, which later became such a common sight in London and the provincial cities, that is proving the forerunner of a new source of illumination. Yet the early experiments of the men who have contributed toward making possible this great commercial asset are almost forgotten and their names are seldom mentioned in connection with the industry of which they are virtually the founders.

Discovery of Rare Gases

In the middle of the seventeenth century Robert Boyle attempted to analyse the true nature of the atmosphere, but the presence of rare inert gases was not suspected until two centuries later when in 1868 Sir Joseph Lockyer, the astronomer, detected helium in the sun. Lord Rayleigh and Sir William Ramsay discovered a new gas, argon, in 1894 and in the following year definitely established the fact that helium occurred in terrestrial matter.

Whilst searching for still more gases, Ramsay succeeding in isolating neon, krypton and xenon for the first time in 1897, thus revealing to science the complete series of rare gases.

"Geissler" and "Moore" Tubes

Following on the disovery of argon and helium, a German glassblower named Heinrich Geissler invented a sealed glass tube for examining the passage of an electric current through rarefied gases. So beautiful were the effects obtained from these "Geissler Tubes", that they were constructed in the form of a decorative display to commemorate the Diamond Jubilee of Queen Victoria.

Realising the possibilities of these tubes for application to commercial purposes, D. MacFarlen Moore, a resident of Newark, U.S.A., began to experiment, using carbon dioxide and nitrogen, and during the early part of the present century many "Moore Tube Signs" were installed. Since the tubes could only be made with large diameters, were necessarily of considerable length and presented a great many technical problems, their cost was excessive and their application limited.

Neon Signs

In 1910 Georges Claude, the famous French inventor, demonstrated at the Grand Palais in Paris, the first neon sign utilising the fundamental principles of those operating under present-day conditions. It was not until 1915, however, that patent rights were granted him, and during the interval the outbreak of the Great War created economic crises which rendered futile any immediate progress in this direction. Strangely enough the development of the neon tube for lighting purposes was again to be arrested some twenty-five years later under similar circumstances.

Progress was extremely slow in the years following the World War, but by 1926 several firms were licensed under the Claude patents and neon tubes began to replace incandescent lamps for signs in many of the larger cities. The peculiar arresting-power and low running cost of luminous tube signs together created such a public demand that independent companies were formed for their manufacture. The ensuing lawsuits resulting from this exploitation only served to declare invalid the majority of patent claims and the last of these latter (covering the size of electrodes) expired in 1932.

Although Claude may be said to be responsible for the commercial introduction of neon-filled luminous discharge tubes, the foundation of the principles underlying the phenomenon can be attributed to scientists too numerous to mention. Michael Faraday, Sir William Crookes, Sir Joseph J. Thomson and a host of others have shed much light on the subject of electrical discharge through gases, and have been indirectly instrumental in paving a way to the rapidly growing luminous tube industry as we know it to-day.

Elementary Experiments

If two metallic electrodes are sealed into a small glass container as shown in Fig. 1A and connected to a continuous source of supply which permits of a steady increase of P.D., it will be found that the first form of discharge is of the type known as a Brush

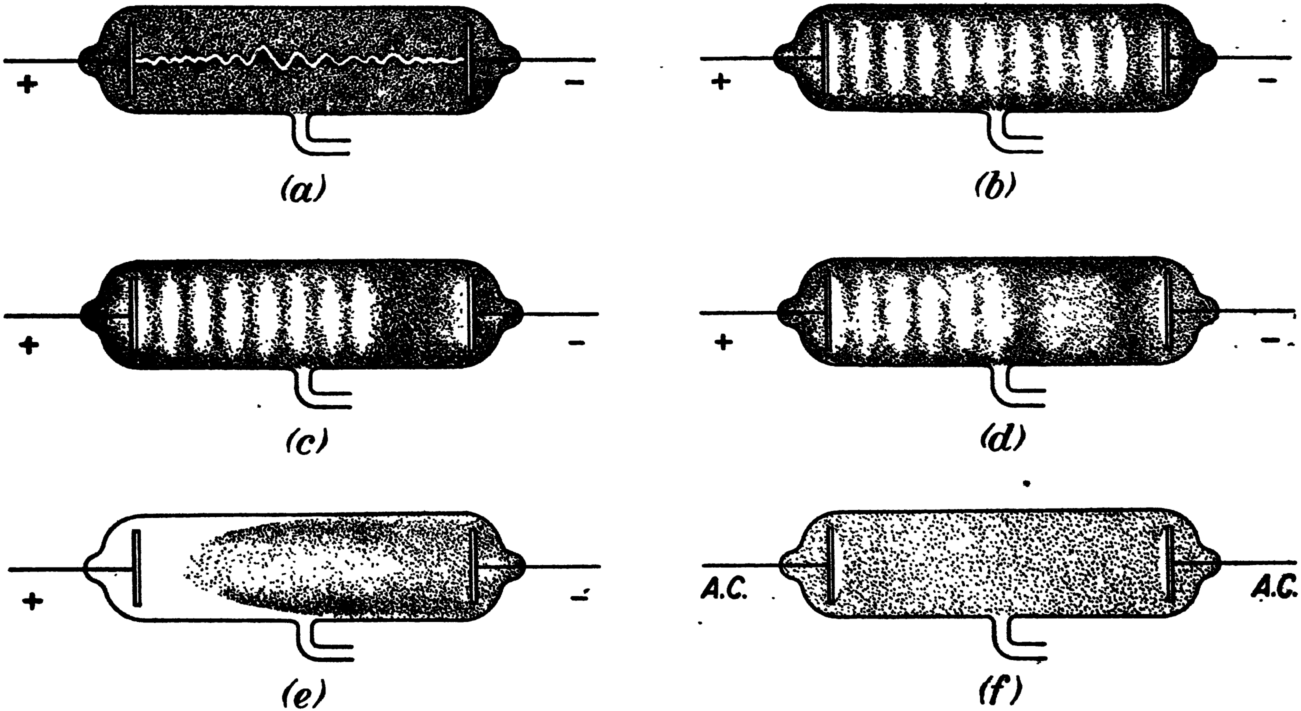


Fig. 1.—Faraday and Crookes Dark Space

(a) Spark discharge (b) Geissler tube (c) Faraday dark space (d) Crookes dark space (e) Fluorescence (f) A.C. discharge

Discharge and consists of a violet glow accompanied by a faint, hissing noise.

Spark Discharge

As the potential is increased, the noise will develop into a crackling sound and the more familiar Spark Discharge, similar to a succession of miniature flashes of lightning, will occur.

The tube is now connected with capillary glass tubing to a high vacuum pump and exhausted to about one half of the atmospheric pressure. The crackling nature of the discharge ceases and assumes the form of a silent pink streamer which spreads out on further reduction of pressure until it fills the tube. At this stage the arrangement is known as a Geissler tube, after the inventor previously mentioned, and is highly luminous (see Fig. 1B). The necessary difference of potential required to maintain the discharge is very much lower than was the case for discharge at atmospheric pressure.

Faraday Dark Space

On further reduction of pressure a dark patch will be observed to surround the cathode (negative electrode), separated from it by a bluish glow and becoming more pronounced with decrease of pressure. This dark patch, shown in Fig. 1C, is called the Faraday Dark Space, and extending from it right up to the anode or positive electrode is a pinkish stream of striations known as the positive column.

Crookes Dark Space

When the pressure reaches a definite point, further changes take place; the bluish glow around the cathode increasing in volume and directly surrounding the cathode a further dark space will be seen (Fig. 1D). This was first discovered by Sir William Crookes, a British scientist, and is therefore named the Crookes Dark Space. The Faraday Dark Space will also have been found to increase and the disc-shaped striations forming the positive column will be fewer in number but larger and more distinct.

Subsequent reduction of pressure results in a gradual diminishing of the striations, cathode glow and Faraday Dark Space with a corresponding swelling of the Crookes Dark Space until only the latter and a luminous border are present as shown in Fig. 1E. The colour of this luminous, or fluorescent boundary depends on the kind of glass comprising the container, being bright green in soda glass and blue in lead glass.

Cathode Rays

This effect (fluorescence), which has proved to be an extremely important part of luminous tube technique, has been found to be due to rays travelling in straight lines from the cathode, which are hence called cathode rays. The cathode rays are now identified as electrons and possess a number of properties comprising mechanical, heating and magnetic effects, but by far the most remarkable property is that of the radiation emitted whenever the rays strike any material substance.

A.C. Discharge

If the electrodes be now connected to a source of alternating current in place of continuous, as Fig. 1F, the stream of disc-shaped striations will be replaced by an evenly distributed glow due to the cyclic variation of the current. This is obviously a more desirable effect from an illumination point of view.

Cause of Illumination

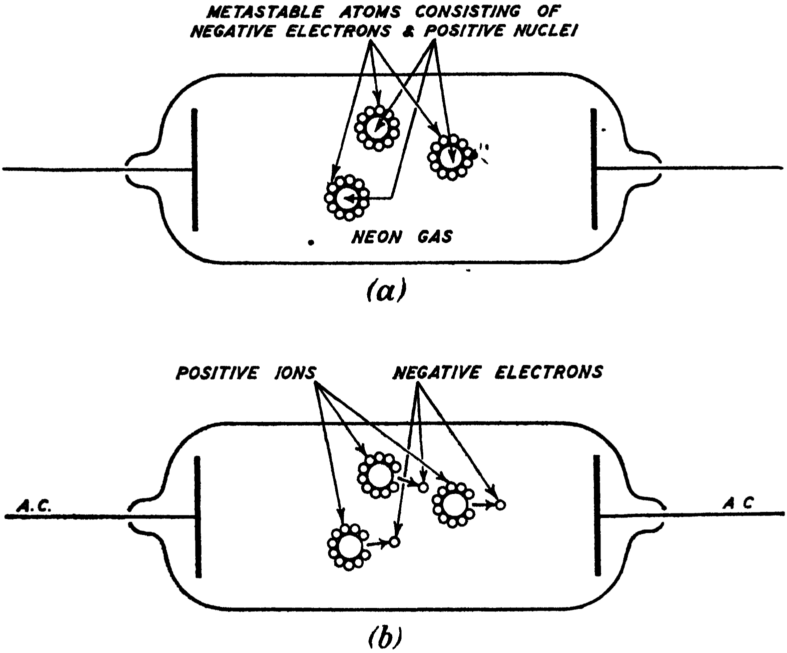
The glow in the tube just described is set up by the projection of free electrons from the cathode and the ionisation of the gas. The conditions upon which ionisation depends require some knowledge of atomic physics for their explanation.

Each molecule of gas, or any other substance for that matter, consists of at least two atoms bound together by electrons or negative charges of electricity, except in a few special cases, for example, mercury vapour and the inert gases, which are monatomic; in these, a single molecule of the element consists of a single atom. Each atom consists of a positive nucleus surrounded by the number of electrons necessary to neutralise its charge as shown diagrammatically in Fig. 2. There are 92 different kinds of nuclei, one for each chemical element, all comprising various charges.

If one or more electrons are detached from an atom, the remaining particle is an ion which, for our particular purpose, we may take as positive.

When an electron obtains additional energy it is said to be excited and, if the energy is sufficient to free the electron entirely from its atom, ionisation takes place. Assuming that current is applied to our discharge tube, providing the voltage is sufficient, atoms of gas will become ionised by collision, thus splitting up into ions and slow electrons.

An electron, having been separated from its atom, cannot re-combine with the ion until it has lost the surplus energy. In a high pressure discharge (e.g., in mercury vapour lamps), this energy is imparted to another particle, but in a low pressure discharge (neon, argon-with-mercury, or helium tubes), re-combination often takes place at the wall of the tube. An argon or mercury atom may be ionised by a neon atom, known as a "metastable" atom. Finally, if the energy imparted is of a high order, electrons can be directly knocked out by fast positive ions (represented by Fig. 3).


METASTABLE ATOMS CONSISTING OF NEGATIVE ELECTRONS & POSITIVE NUCLEI
NEON GAS
(a)
POSITIVE IONS
NEGATIVE ELECTRONS
A.C.
A C
(b)

FIGS. 2 (top) and 3 (bottom).—METASTABLE ATOMS
(a) Before current is applied (b) After ionisation

From our luminous tube point of view the metastable state is of great importance, particularly on account of fluorescent effects in neon-filled tubes.

It is the surplus energy of the excited atom that supplies the light of our discharge tube, the difference being radiated in the form of a photon or light quantum. Atoms of different gases have different characteristic spectra, and the frequency of the light emitted is, as we shall see later, directly proportional to the energy difference.

The period that elapses before the photon is emitted from the excited atom is known as the time constant. Metastable atoms are known to have very long time constants (from 0·1 to 10·0 seconds), so that an excited neon atom has time to collide with thousands of other atoms before reaching the glass wall or emitting a photon. In effect, the metastable atom in a neon discharge tube appears to form a separate gas which is readily ionised and rendered a conductor of the electric current. The highly ionised gas was called by Langmuir the "plasma", and is supposed to contain normally equal numbers of positive and negative charges per unit volume.

In high pressure discharge lamps the plasma is indicated by a thin, intensely luminous cord through the centre, but in low pressure luminous tubes this takes the form of a uniformly luminous region through the length of the tube, with the exception of a distance of from 1 to 2 tube diameters from the electrodes and a thin space charge at the walls.

Langmuir discovered that the electrons in the plasma have a Maxwellian distribution of velocities and are much faster than the ions.

Assuming that the plasma were to completely fill the tube, more electrons would reach the wall than ions. Actually the wall becomes negatively charged and this condition is neutralised by a thin sheath near the wall containing an excess of positive ions.

Theoretically, the plasma may be regarded as being constituted of three gases, neutral gas, ion gas, and electron gas; the neutral gas being made up of atoms in differently excited states of which the metastables are the most important.

From the preceding notes, we can sum up the action of the discharge tube as follows:

Excitation.—The application of the electric current at a definite potential (First Excitation Potential), has the effect of supplying additional energy to each atom of gas.

Ionisation.—Provided that the voltage is sufficient (Ionisation Potential), the energy acquired displaces one or more electrons of the atom, thereby splitting up the gas into ions and free electrons (Plasma).

Radiation.—The resulting collision of particles causes the surplus energy to be emitted as light, the spectra of which is dependent on the gas.

The striking or ionisation potential of a luminous tube depends on a number of factors, including the working length of the tube, the nature and pressure of the gas or vapour it contains and some items of manufacture, particularly concerning electrodes.

Naturally, the greater the distance between the electrodes of a particular tube, the higher will be the striking voltage; the operating voltage is in all cases lower than the striking potential.

The majority of the luminous tubes referred to herein are of the cold-cathode, high-voltage type, having a wave-form similar to that shown in Fig. 4, which applies to tubing operated by a fully-loaded transformer, the dotted line representing the no-load voltage.

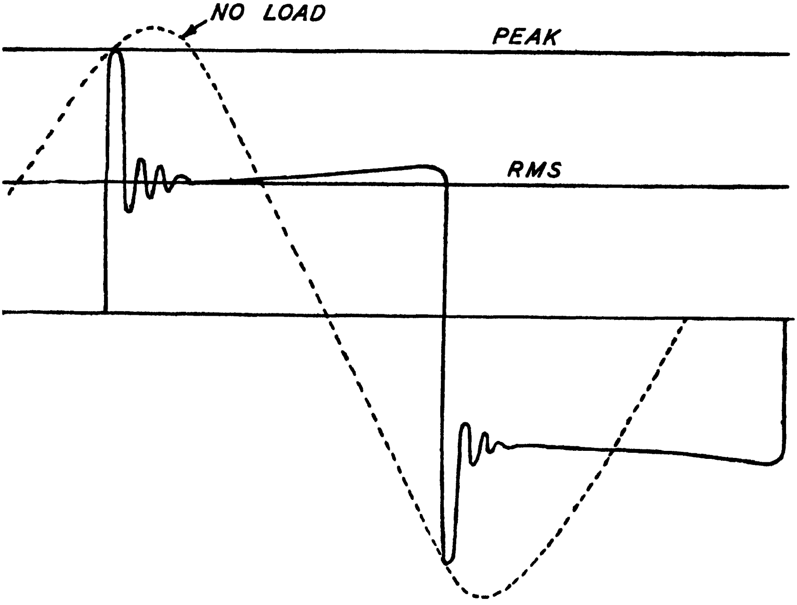


Fig. 4.—Wave-form of High-Voltage Cold-Cathode Luminous Tube

Immediately after ionisation the voltage drops rapidly and high frequency currents in the neighbourhood of 2,000 to 3,000 cycles are encountered for a period of each half-cycle before a stable condition is reached. A transformer of the constant current type is therefore required.

Fig. 5, which is self-explanatory, shows the effect on current of gradually increasing the pressure inside a neon-filled tube operated at constant voltage. The average pressure for such a tube is about 11 millimetres of mercury, whilst with helium a pressure as high as 20 millimetres is sometimes used.

In processing luminous tubes a great deal depends on the experience of the operative, who should be able to more or less judge the state of partial vacuum from the appearance of the discharge. Table 1 shows the results observed on exhausting a standard discharge tube.

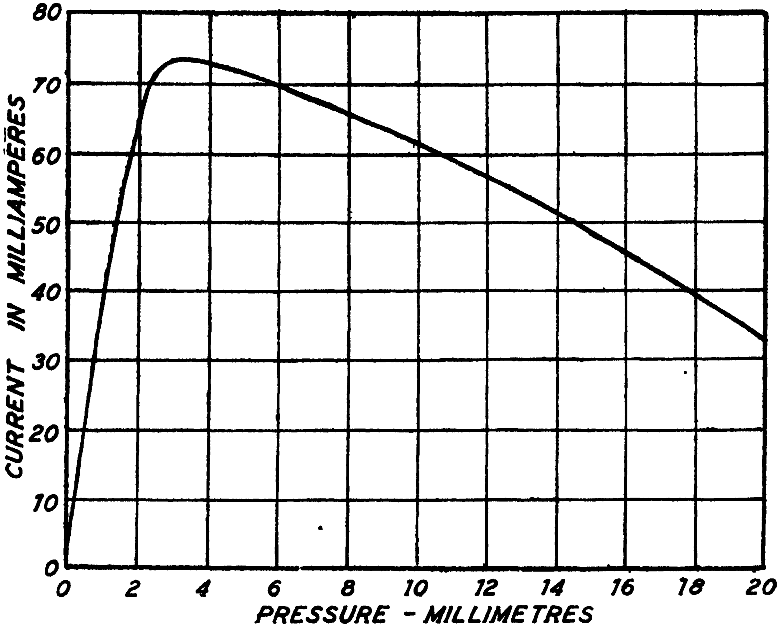


Fig. 5.—Effect on Current as Pressure is Gradually Increased

TABLE 1

APPROXIMATE GAS PRESSURES AS SHOWN BY STANDARD DISCHARGE TUBE INDICATOR

Appearance of Glow Discharge	Approximate Pressure
½ cm. dia. glow down centre of tube	10 mm.
¾ cm. dia. glow down centre of tube	5 mm.
Striations commence (very close)	1½ mm.
Striations ¾ cm. apart	1 mm.
Striations 1 cm. apart	½ mm.
Dark space appears and luminosity suddenly decreases	0·2 mm.
Green fluorescence	0·01 mm.
Black-out in dark (when tube is not full of air)	0·001 mm. (or less)

A pink discharge usually signifies that the gas is largely air.

A bluish-grey discharge is usually due to the presence of organic vapours.

Luminous Tube Light Sources

The modern trend in illuminating technique is to provide a source of lighting which is both efficient and decorative. By tracing the development of electric light sources through the various stages of carbon, squirted filament, drawn wire and mercury and sodium vapour, it is obvious that we must look upon the discharge lamp as the light of the future. It only remains to decide the form of discharge lamp to be adopted.

Although high pressure mercury and sodium vapour lamps appear to fulfil both conditions mentioned above as necessary in a modern illuminant, the inherent colour difficulty renders them impractical for general utility. Any attempt at true colour correction has so far been found to reduce their efficiency.

Advantages

Considering the low pressure discharge tube (familarly known by what is frequently a misnomer, as a "neon tube")—from an illumination point of view this type of luminous tube has three obvious advantages over the other lamps mentioned. These are:

(1) being in tube form, it can be bent into the shape or design required to harmonise with any given scheme of decoration;

(2) it is a longitudinal light source and can therefore be made to give even diffusion without the aid of dispersive fittings; and

(3) The heating produced is negligible.

Although its efficiency is somewhat lower than that of high pressure discharge lamps, luminous tube lighting does not have their deficiency in red rays and has a longer life. A factor which impedes the general adoption of luminous tubes for illumination is the comparatively high installation cost. This is mainly due to the expense of high voltage wiring and equipment, for there is no reason why, when once luminous tubes are standardised for lighting, they should not be produced at a price which would compare favourably with that of filament lamps.

Potential schemes of decorative lighting, both direct and indirect, by means of high-voltage luminous discharge tubes are legion; in cornices, behind frosted glass panels or arranged in pictorial design on friezes. The possibilities are, in fact, innumerable.

Chapter 2

THEORETICAL CONSIDERATIONS

If we revert to our sealed gas-filled tube with two electrodes to which has been applied a continuous and steadily increasing source of electric supply, we see that only a minute current passes until a definite potential (Sparking Potential), has been reached. Then, once the resistance of the medium has been overcome, the passage of the current is accompanied by the emission of radiation.

INITIATION OF THE DISCHARGE[1]

The precise explanation of what has occurred in the tube is still to some extent a matter of conjecture, but the initiation of the discharge can be best understood by considering a single electron.

If we imagine the electron starting from the cathode, and assume that it generates another n electrons during its passage to the anode, then, if the effect of lateral diffusion to the walls of the tube is neglected, the corresponding number of positive ions arriving at the anode will also be n. Let us also suppose that each of these excites the emission of another f electrons. The product fn must always be greater than unity if the discharge is to be maintained and, since n is to a great extent dependent on the gas pressure p and the applied voltage V, there is obviously a relation between p and f and the sparking potential V_c. This is an equation of the form

$$V_c = \phi\,(pd\,.\,f)$$

in which d is the electrode spacing.

Slight changes in the composition of the gas have been found to alter the sparking potential considerably. In the case of an inert gas at several millimetres pressure, the presence of mercury vapour at a partial pressure of a hundredth of a millimetre of mercury has lowered the sparking potential by between 300 and 400 volts. This can be better understood by considering that an excited atom of helium, for example, requires 19·8 electron-volts for ionisation whereas only 10·4 electron-volts is required for mercury.

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[1] Vide *The Conduction of Electricity Through Gases*, by K. G. Emelius, M.A., Ph.D. (Methuen & Co , Ltd.).

Although not apparent in practice, there is an appreciable time-lag between the application of the potential and the passage of a self-maintained current through the tube. It is variable and is largely dependent on the difference between the sparking and applied potentials. The condition of the surface of the cathode also affects the lag to some extent in a similar manner to the polarisation and subsequent production of back e.m.f. in an electrolytic cell. This is usually due to a coating of some poorly conducting material on the surface of the cathode or, in some instances, layers of gas.

The lag, which may be less than a millionth of a second, is found to be reduced when the cathode has been exposed to a high-frequency ultra-violet light which is capable of liberating photo-electrons from the metal.

Probability of Ionisation

The representation of the probability of ionisation at a collision is an almost linear increase from zero at the ionisation potential to about three times this. Beyond this, which is roughly the maximum, the increase falls off gradually. In helium, one collision in four results in the formation of a positive ion at a potential of 180 volts.

Atoms and molecules after collision behave similarly, except that excitation of a molecule may produce an unstable excited molecule which dissociates spontaneously into atoms.

An excited atomic system does not necessarily emit radiation when it returns to the normal state, as the energy available may be used to excite another system of lower excitation potential. In this case, the excess is utilised in augmenting the relative translatory motion of the two reacting particles, being distributed between them so that momentum is conserved. A simple example of this is furnished by the so-called sensitised fluorescence of thallium vapour.

Normally, thallium vapour cannot be excited by exposure to a source of mercury resonance radiation at 2537Å, but if a small quantity of mercury vapour is introduced a green fluorescence is produced immediately. The process responsible for this is often termed a collision of the second kind and consists of the absorption of its own resonance radiation by the mercury, the energy being passed on to the thallium in collision, giving a normal mercury atom and an atom of thallium in an excited state.

Mean Free Paths

The mean free path for the neutral molecules is $4\sqrt{2}$ according to simple kinetic theory, and it follows that this should also apply to electrons insofar as inelastic collisions are concerned. Although this is true in the case of electrons with speeds of between 30 and 200 volts, it is not applicable to slow electrons, especially in the inert gases. There is evidence, however, that some positive ions of the same speeds as the slow electrons have similar variations of the mean free path.

If 1 is taken as the mean value of distance about which molecules move between collisions, the mean free paths are as shown in Table 2.

TABLE 2

Mean Free Paths of Neutral Molecules in Tenths of a Millimetre from Measurements of the Viscosity

Gas	H_2	O_2	N_2	A	He	H_2O
1	1·2	0·7	0·6	0·7	1·9	0·4

This refers to neutral molecules moving amongst molecules of a similar kind at a temperature of 0° C. and at a pressure of 1 millimetre of mercury.

Hot-Cathode Tube

If a continuous current of electrons is passed from a hot filament or cathode through mercury vapour, blue-green striae will appear. The number of striae is increased in proportion to the difference of potential, and it is found that a new striation appears for each increase of potential of 4·9 volts, due to the elastic rebounding of the electrons.

Since the mass of an electron is 3×10^{-6} that of a mercury atom, the numerous collisions, which are first elastic, involve only a minute transfer of energy. Hence, some of these collisions cease to be elastic at the 4·9 volt equipotential surface and the whole of the energy of an electron is transferred to a mercury atom. The pressure of the vapour is such that almost all the electrons are reduced to rest by inelastic collisions in the first striation.

In the case of excitation under the influence of radiation, the energy of the quantum of the latter must, of course, be at least 4·9 electron-volts. An uncombined atom in mercury vapour would require the emission of ultra-violet radiation of wavelength 2537Å in order to return to its normal state in one single jump after being excited by energy of 4·9 electron-volts. When mercury vapour at low pressure is exposed to such radiation no visible radiation is produced.

MECHANISM OF THE POSITIVE COLUMN[1]

There is a continual loss of electrons in the positive column of a gaseous discharge due to diffusion to the sides of the tube, formation of negative ions (except with neon, helium or argon), formation of neutral atoms or molecules, ionisation of the gas, excitation of luminosity and inelastic collisions.

Obviously, for the discharge to continue there must be a regular supply both of new electrons and of energy. Considering the loss through diffusion, the electrons diffuse more rapidly than the positive ions so that the surface of the discharge tube becomes negatively electrified. The positive ions are therefore attracted to the wall of the tube forming what Langmuir (the inventor of the gas-filled lamp) called a "sheath" to the accumulated negative charge.

The diffusion of the electrons is normally balanced by the movement of positive ions to the sheath and the electric field in the gas is unaffected. Sir Joseph Thomson found that the rate at which the gas loses electrons by diffusion to the wall of the glass is

$$2\pi \,.\, a\, dx \,.\, \frac{nC}{\sqrt{6\pi}}$$

in which C is the velocity of mean square of the positive ions and n their density, a being the inner radius of the tube.

Considering the loss occasioned by the formation of negative ions, this depends on the nature of the gas. Neon, helium and argon do not form negative ions so that this aspect does not concern us to any great extent. It is known that a number of collisions must be made by an electron before production of a negative ion, the precise number being dependent on the gas itself and bearing no relation to the pressure.

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[1] Vide *The Conduction of Electricity Through Gases*, by Sir J. J. Thomson, O.M., F.R.S., and G. P. Thomson, M.A., F.R.S.

If L is the free path of the electron, the chance of its making a collision in a distance dx is dx/L and if the electron has to make N collisions before it unites with a molecule to form a negative ion, the chance that the electron is captured in going through the distance dx is

$$\frac{dx}{NL} \times \frac{U}{u}$$

in which U is the velocity of mean square of the electrons. The factor U/u has to be inserted because the electron, when it goes from one point to another, traverses, owing to the deflection of its path, a much greater length than the shortest distance between two points.

In the case of a glow discharge the loss due to the combination of an electron with a positive ion is comparatively small since the number of positive ions is very much less than the number of uncharged molecules.

Potential Gradient

The diminution in density of the gas is to some extent brought about by the heating effect of the current, although this is not sufficient to account for the whole of the decrease in the potential gradient. With a potential difference between the electrodes of 1,000 volts and a current of 0·1 ampere the heat produced in the tube would be about 25 calories per second.

Potential gradients in the positive column are given in Table 3, which is due to Matthies.

TABLE 3

Current through tube 0·25 *milliampere. Diameter of tube* 3·5 *cm.*

PRESSURE in mm. of Hg.	POTENTIAL GRADIENT IN VOLTS PER CM.					
	Cl_2	Br_2	$HgCl_2$	HgI_2	I_2	N_2
0·1	25	—	38	29	—	—
0·4	40	45	66	53	50	17
0·9	72	98	127	114	64	32
1·4	120	145	150	147	75	43
1·9	139	170	202	165	110	54
2·35	175	295	222	188	142	62
3·0	200	221	263	251	200	77

The potential gradient depends on (1) the diameter of the discharge tube; (2) the pressure and nature of the gas through which the discharge is passing; and (3) the current through the gas. It is much affected by impurities in the gas and is extremely susceptible to changes in pressure and in current. When the discharge is intermittent the gradient measured is the mean value of the potential gradient in the luminous positive column and the one where the discharge is interrupted.

Any increase in the current will increase the luminosity and radiation emitted by the gas, which is equivalent to a diminution in the ionisation potential and consequently the gradient. In addition, the interval between any two collisions would be diminished, thus increasing the probability of ionisation.

Again, the current may, in some cases, prevent the formation of negative ions or detach the electron as soon as the ions were made, thereby lessening the loss of electrons by combination with molecules. The energy required to detach an electron from a negative ion must be small compared with the ionisation potential and the light quanta from the brilliant luminosity produced by the current might be sufficient to detach an electron from a negative ion though not from an uncharged molecule.

The relation between gradient and pressure is linear for small pressures and current densities, although there is a slight variation in the case of large current densities and high pressures.

OPTICAL CONSIDERATIONS

Quantum Theory

Until the beginning of the present century the vast majority of physicists were content to abide by Newton's dynamical laws which they considered as something established for all time. Phenomena such as black body radiation and line spectra have since shown that there are some types of radiation that cannot be accounted for on the basis of the classical theory.

A black body may be defined as any body with a surface that absorbs radiation of any wavelength whatever that may fall on it. At some definite temperature it is found that the radiation from a black body resembles that inside a vacuous enclosure (not containing atoms or molecules) at this temperature, the character of the radiation being independent of the material of which the walls are assumed to be made. This was one of the problems engaging scientists early in the twentieth century.

The introduction of a new conception of the atom is due to Max Planck who averred that radiant energy did not consist of transverse waves in the ether, but of minute pulses of energy called "quanta" According to this doctrine, radiation can be produced by acceleration of electric charges in the atom. The luminous discharge tube is, of course, an instance of this.

It is considered that atoms consist of a central nucleus with a number of electrons moving round the nucleus in different orbits. Under certain conditions, as for example in the case of fluorescent substances, the action of light on the atoms is to cause some of the electrons to jump from an orbit of low energy into an orbit of greater energy. When the light source is removed, these electrons jump back into their original orbits and, in doing so, release quanta of energy which appears as visible light or phosphorescence.

In the case of gaseous discharge tubes, it is probable that the luminous effect is caused by the somewhat similar disturbances of the electron orbits in the molecules of the gas. The exact relation of the quantum theory to the conduction of electricity through gases has been investigated by Planck, Boltzmann and Bohr. Bohr has, in fact, investigated the quantum theory with particular reference to the actions occurring during the conduction of electricity through rarefied gases. It has been established that, when an electron jumps from one orbit into another orbit of smaller radius, a light ray of definite wavelength is emitted, the wavelength and hence the quality of the emitted light depend upon the physical properties of the gas and also the conditions under which the excitation is applied to it.

Light and Vision

We cannot see light. We can see the object from which it comes, yet the actual light ray is invisible. From the preceding descriptions we know that light can be caused by the motion of electrons and, according to Planck, consists of minute pulses of energy. At one time—not so very long ago—light was considered as a series of waves. Subsequent experiments, as we have just seen, have shown that under certain conditions light, like the electrons, behaved like particles.

At all events, light is a form of energy which radiates in straight lines: of this much we are certain. Also, when it falls upon an object it is partly absorbed and partly redirected in various ways. It is this redirected light that enters the eye and is focused on to the retina and energising. the optic nerves.

Light can therefore be considered as two elements: (1) the actual radiation; and (2) the mechanism in the eye which receives it and passes it on to the brain.

We have already dealt in some measure with the actual radiation. Concerning the eye itself, we know that it is a sensitive organ. It contains a lens which we are able to adjust by means of muscles for correct focus and size of aperture.

While visual acuity increases up to a point with increasing illumination, temporary reductions in sensitivity occur whenever the eye is turned from a bright to a less bright surface, according to the degree of contrast. Similarly, ease of vision over the rest of the field is diminished if there is a very bright area in the field of view. This condition is known as glare, and leads to discomfort, fatigue and, in an intense form, injury to the eye.

Good lighting must therefore prevent the sensation of too great a brightness and be reasonably uniform in order to prevent overwork or "strain" to the eyes. For both of these points luminous tube lighting has an obvious advantage over point sources of light.

Wavelength

It is convenient to consider all radiation as consisting of a periodic disturbance propagated with a definite velocity. For radiation at a velocity v with a frequency f the quality is expressed as v/f. This quotient (λ) is called the "wavelength" of the radiation.

The wavelength of the visible spectrum, with which we are principally concerned, is between the limits ·4 and ·75 thousandths of a millimetre (usually expressed as $0{\cdot}4\mu$ to $0{\cdot}75\mu$). The response of the eye varies according to the particular wavelength of the radiation, thereby evoking the sensation of "colour". For instance, radiation with a wavelength of $0{\cdot}7\mu$ produces a sensation of red light, whilst at $0{\cdot}4\mu$ the colour would appear as violet. For intermediate wavelengths the colours would be orange, yellow, green and blue.

Of course the radiations are rarely homogeneous. More often than not they consist of a mixture containing some of each of the range mentioned above.

Luminous Flux and Intensity

The quantitative term for light is "luminous flux", which may be defined as the rate of passage of radiant energy evaluated by reference to the luminous sensation produced by it. It is expressed in "lumens".

The luminous flux will be dependent upon the relative luminosity factor, the power absorbed by the light source, and the wavelength of radiation.

It will be appreciated that, in actual practice, the radiation from any given light source covers a wide range of wavelengths, e.g., from about 4,500 to about 6,500 Ångström units. In this connection reference should be made to Fig. 6, where the qualities of light corresponding to various wavelengths are indicated.

Radiations having a wavelength shorter than 4,000 Ångström units are ultra-violet and therefore invisible. At the other end of the scale, radiations of wavelengths exceeding 7,000 Ångström units are infra-red and therefore invisible, though perceptible as heat rays.

Considering a point source of light which is radiating energy at a constant rate in all directions, the luminous flux, F may be expressed

$$F \propto I\omega$$

in which I is the rate at which the source is emitting light and ω the solid angle enclosed within a cone having the source as apex. I is called the "luminous intensity" of the source and is given in candle-power.

In the case of luminous tubing the source cannot be considered as emanating from a point and the calculation of luminous intensity presents more difficulty. An example of this is given in the chapter entitled "Data and Tests".

Illumination

The illumination or the number of "foot-candles" at a surface is defined as the "luminous flux per unit area of evenly illuminated surface". It is with illumination that the familiar "inverse square" and "cosine" laws for light are usually associated. Briefly stated, these are (1) the intensity of illumination due to a point source of light varies inversely as the square of the distance from the source; and (2) the illumination at any point on a surface is proportional to the cosine of the angle of incidence of the light rays at that point.

One foot-candle is the illumination produced by a source of one candle-power at a distance of one foot.

Illumination from Luminous Tubing

It is rather difficult to obtain reasonably accurate illumination measurements of most luminous tubes, as the light frequencies emitted are of a narrow band. The eye does not respond with same degree of sensitivity to all colours (see Fig. 6), so that the average foot-candle meter, which is usually calibrated with a white light source, is not accurate enough for coloured lights. In other words, the sensitivity of the photo-cell used in the foot-candle instrument does not follow the same peaked curve, indicated in Fig. 6, as the eye sensitivity.

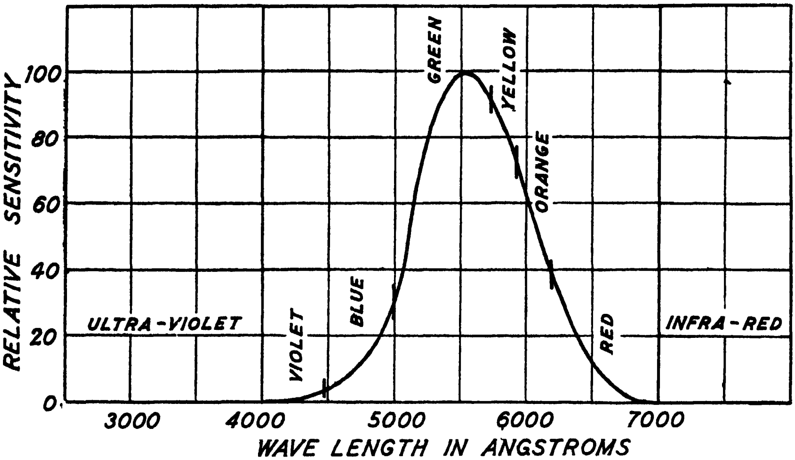


FIG. 6.—GRAPH OF AVERAGE EYE SENSITIVITY

Table 4 shows the correction factors that must be applied to measurements made with the Weston Foot-candle Meter for (*a*) low voltage type fluorescent tubes, and (*b*) the corresponding factors for high voltage luminous discharge tubes.

TABLE 4

	Light meter cell without filter CORRECTION FACTOR	Light meter cell with Viscor filter CORRECTION FACTOR
(*a*) LOW VOLTAGE FLUORESCENT TUBES		
Daylight	1·05	1·00
White	1·18	1·00
Pink	1·22	1·00
Gold	1·34	0·995
Green	1·55	0·987
Blue	0·615	1·00
Red	0·498	1·015
(*b*) HIGH VOLTAGE GASEOUS TUBES		
Neon red (clear tube)	0·94	1·005
Helium yellow tube	1·37	0·993
Mercury blue (clear tube) ..	1·15	1·004

It will be noticed that the correction factors are given: (1) unfiltered, and (2) using Weston Viscor Filter, which is used to approximate the human eye response and is really necessary for reliable results. The foot-candles indicated by the instrument should be multiplied by the correction factors set forth in the table.

Since the wavelengths of gaseous discharge tubing are to some extent dependent on gas pressure and other factors, there is still a possibility of error. Also the age of the tube, particularly in the case of fluorescent types, effects the emission, thereby making it difficult to determine the spectral composition for any one tube throughout life.

Brightness

Since this concerns one of the main advantages of luminous tube lighting as compared with other sources, it is proposed to give some definitions.

Brightness, or the luminous intensity of unit projected area of a surface, is expressed in candles per unit area. It may be applied either to the actual light emission or to reflection. In the case of reflection the character of the surface is of great importance in arriving at the correct brightness, since surfaces have both quantitative and qualitative differences in reflection values. A surface that scatters light and thus presents an appearance of even brightness is termed a "perfect diffuser".

The least difference in brightness of surfaces which the eye can detect is known as the "brightness-difference threshold" (B.D.T.).

It is sometimes taken as a measure of the sensitiveness of the eye in adapting itself to varying conditions of brightness. This brings us to the production of the result familiarly called "glare". Glare naturally has considerable effect on B.D.T., for it is well known that a bright source of light in the field of vision reduces the sensitivity of the eye. In some cases this reduction amounts to as much as sixty per cent.

Chapter 3

MATERIALS

GLASS

SINCE the most obvious component of a luminous tube is the glass envelope, it is proposed to deal with this first.

A concise definition of glass is not easy, as the term is applied to both a state and a substance. It is sometimes described as a non-crystalline transparent mixture of fused silicates or, scientifically, as a super-cooled liquid or solution, colloidal in nature, and of high viscosity. In the case of glasses for luminous tube work certain well-marked characteristics are apparent, some of which are common to solids.

Probably the most important of the properties of glass is its viscosity. On this depend all the methods of manipulation; blowing, bending and drawing out. The determination of viscosity presents peculiar experimental difficulties on account of the enormous variation in the value of this property in a range of temperatures. Thus, the method of arriving at viscosity depends on the temperature range explored. On this account it is far safer (and incidentally of far more use to the glassblower) to give the high annealing temperature for a glass rather than its softening point.

The reference to annealing perhaps needs some explanation. Glass is a poor conductor of heat and if suddenly cooled is liable to break. This is due to outer layers of heated glass setting hard prior to the inner layers, so that any subsequent cooling down and setting is retarded and stresses are set up in the glass. A piece of hot glass tubing can be prevented from developing undue stresses by retarding its rate of cooling appropriately over what is known as the annealing range. Once the temperature falls below the lower limit of this range, the cooling can be rapid without modifying the distribution of stresses.

Viscosity is found to be a function of the chemical composition of the glass but other physical properties, such as annealing temperature and electrical conductivity are not so simply related to the composition. General relationships have, however, been established.

The varieties of glass usually met with in luminous tube work are soft soda, lead and hard glasses.

In general, the requirements of glass tubing for this purpose may be summed up as follows: (1) it should be capable of withstanding changes of temperature; (2) the melting point must be reasonably low, so that it can be easily worked; and (3) it must be as uniform as is possible in diameter and thickness of wall.

Glass tubing is usually supplied in from 4- to 5-foot lengths with the alternative of three wall thicknesses commonly known as "light", "standard" and "heavy" wall. The tubing may be either hand-drawn or machine-drawn.

Soda or Sodalime Glass

Soft soda glass is commonly used in vacuum technique in this country, the particular advantage being its low melting point. Although its composition varies in different manufactures, the proportion of oxide mixtures is roughly:

SiO_2	..	68%
K_2O	..	2%
Na_2O	..	18%
CaO	..	6%
Al_2O_3	..	4%
MgO	..	1%
B_2O_3	..	2%

The coefficient of expansion of soft soda glass is $10 \cdot 1 \times 10^{-6}$ per degree Centigrade, specific gravity 2·49 and high annealing temperature 500° C. Owing to the comparatively low melting point, it can be worked quite satisfactorily in a coal gas with compressed air flame.

Lead Glass

Manufacturers in the United States prefer lead glass to soda glass for luminous tube work. It is slightly dearer and contains a considerable amount of lead oxide from which it derives its name. It is not widely used for the actual wall of luminous tubes in this country and requires a special cross-fire lamp for successful working.

Dialume

Dialume Green Glass, which is manufactured by Messrs. Plowden & Thompson, Ltd., of Stourbridge (Worcs.), has been designed to give the greatest degree of natural luminescence combined with resistance to blackening by mercury deposit, and at the same time to provide a diffused light with as little a loss of absorption as possible. It is somewhat harder than soft soda glass and includes uranium in its composition for the purpose of exciting the ultra-violet radiation of a mercury-argon discharge.

The use of powders coating the insides of glass tubing to give fluorescent effects would appear to be open to the objection that the resulting rough surface affords an anchorage to mercury. Thus, although these powders give brilliant and novel effects, the mercury deposited on the interior of the tubes ultimately tends to dull them. This undesirable effect is obviated in Dialume in which the naturally luminescent element (uranium) is incorporated in the glass in such a way that the optimum composition is reached compatible with ease of working.

The natural fire-polish of the interior surface of Dialume tubing does not absorb undue quantities of gas nor does it give up free alkali. Although its coefficient of expansion is slightly lower than that of soft soda or lead glass, it can be easily worked with coal-gas with compressed air flames and can be satisfactorily joined to these glasses. It can be confidently employed for high intensity luminous tubes.

With a view to comparing the light outputs obtained from cold-cathode discharges in various glasses, the following photometric tests, which were made in 1937 by an independent research association, show the efficiency of Dialume.

TABLE 5

Photometric Tests Using Various Glasses

GLASS	GAS FILLING	COLOUR OF DISCHARGE	OPERATING CURRENT MILLIAMPS.	LIGHT OUTPUT C.P. PER FT.
1. Clear Soda ..	helium	yellow	50	3·25
2. Yellow Cased	helium	gold	50	2·55
3. Clear Soda ..	neon	red	25	2·95
4. Clear Soda ..	argon-mercury	blue	25	2·10
5. Clear Soda Green	argon-mercury	green	25	1·20
6. Dialume Green	argon-mercury	green	25	6·00
7. Lumophor Green No. 5B ..	argon-mercury	green	25	4·90
8. Lumophor Green No. 627 ..	argon-mercury	green	25	5·55

The makers of Dialume also supply a clear, colourless soda-glass of the non-deposit type called Neon Soda, and a 3-ply white opal of the same composition.

Other Coloured Glasses

The same manufacturers include in their range tubing of the following colours:

Canary yellow.
Blue, clear and opal-ply.
Red, clear and opal-ply.
Orange, yolk-of-egg, 3-ply.
Ultra-violet passing.
Violet.
Golden yellow.
Blue-purple.

Phoenix

This is a borosilicate glass manufactured by the British Heat Resisting Glass Company of Bilston and marketed by Messrs. Plowden & Thompson, Ltd. It has a linear thermal expansion of from $3{\cdot}59 \times 10^{-6}$ to $3{\cdot}30 \times 10^{-6}$ between temperature limits 0 to 480° C., and an annealing temperature of 589° C.

Phoenix is the latest of the so-called "hard" glasses which have been successfully developed over the last twenty years or so. It should for convenience be worked with oxygen and, whilst some annealing improves it, this is not so important as with softer glasses.

The working properties of any glass depend quite largely on how it has been melted and manufactured and, in the case of Phoenix, the modern high temperature furnaces and equipment installed by its makers have ensured that nothing is lacking from that point of view. Hence, though it is at least as high in silica as any other commercial hard glass, it works more easily than some. The elimination from its composition of materials which are unsuitable to glass-blowing operations has been insisted upon, together with attention to good colour, evenness of diameter and freedom from the stones and knots to which hard glasses are sometimes liable.

The electrical characteristics, calculated by the Department of Glass Technology, Sheffield University, are:

(1) Volume resistivity in vacuo 0% relative humidity (annealed glass).

TEMPERATURE	RESISTIVITY	TEMPERATURE	RESISTIVITY
30°	$2{\cdot}64 \times 10^{14}$	50°	$3{\cdot}01 \times 10^{14}$
35°	$1{\cdot}51 \times 10^{14}$	55°	$1{\cdot}82 \times 10^{14}$
40°	$8{\cdot}66 \times 10^{14}$	60°	$1{\cdot}11 \times 10^{14}$
45°	$5{\cdot}10 \times 10^{14}$		

(2) Surface resistivity at various humidities (annealed glass).

% RELATIVE HUMIDITY	RESISTANCE PER CM.^{2}		
	Spec. 1		Spec. 2
0	$3{\cdot}641 \times 10^{15}$		$3{\cdot}456 \times 10^{15}$
33	$5{\cdot}156 \times 10^{14}$		$3{\cdot}442 \times 10^{14}$
	$5{\cdot}666 \times 10^{14}$	Increasing time of exposure	$3{\cdot}859 \times 10^{14}$
	$6{\cdot}677 \times 10^{14}$		$4{\cdot}991 \times 10^{14}$
62	$6{\cdot}976 \times 10^{11}$		$9{\cdot}287 \times 10^{11}$
	$9{\cdot}718 \times 10^{11}$		$8{\cdot}513 \times 10^{11}$
	$9{\cdot}559 \times 10^{11}$		$8{\cdot}320 \times 10^{11}$
	$1{\cdot}148 \times 10^{10}$		$1{\cdot}050 \times 10^{12}$
81	$3{\cdot}248 \times 10^{9}$		$4{\cdot}545 \times 10^{9}$

Pyrex Brand Glass

The trade name Pyrex identifies various low expansion glass products made by Messrs. James A. Jobling & Co., Ltd., of Sunderland. Pyrex Brand tubing is mechanically stronger than soft glass, and, in consequence of its low coefficient of expansion ($3{\cdot}2 \times 10^{-6}$ or less between 19 and 450° C.), it can be subjected to more sudden changes of temperature, without fracture, than any other type of commercial glass except fused quartz.

The average composition which is, naturally, liable to slight variation between given controllable limits is:

SiO_2	80·8%
B_2O_3	12·0%
Al_2O_3	2·2%
Fe_2O_3	0·05%
Na_2O	4·4%
As_2O_3	0·05%

The high thermal quality of Pyrex Brand glass unfortunately leads to a great deal of abuse of the material. As with every other glass, there is a limit to which it can be heated without the introduction of permanent strain (round about 450° C.), and consequent cracking.

Tubing of small diameter can be worked, rather slowly, in the coal-gas-air flame, but for the larger sizes it is necessary to use a flame enriched with oxygen. It is not possible completely to anneal this glass in the lamp as is the case with normal sodalime glass, and, although a great deal of apparatus can be made with lamp annealing, on big work, or work involving thick sections of glass, the manufacturers strongly recommend that the annealing be carried out in a small kiln. To offset this disadvantage—if it can be considered as a disadvantage—it is not necessary in lampworking Pyrex Brand glass to flame anneal continuously as the work is proceeding; in most cases the work can be carried out without any intermediate lamp annealing whatever.

Some useful physical and electrical characteristics are:

Elasticity Coefficient—620 kg. per sq. mm.
Hardness—Scleroscope, 120.
Specific Gravity—2·25.
Specific Heat—0·20.
Refractive Index—1·4754.
Dispersion—0·00738.
Light Transmission—Higher than the best plate glass.
Dielectric Strength—32 Kv. per 100 mil.
Dielectric Constant—4·48 (30,000 cycles).
Phase Angle Difference—0·16° (30,000 cycles).
Power Factor—0·28% (30,000 cycles).
Electrical Resistivity (Volume)—Greater than 10 ohms per c.c.
Electrical Resistivity (Surface)—at 34% humidity: 10^{14} ohms; at 84% humidity: 14×10^{8} ohms.

Tungsten and molybdenum can be sealed into Pyrex Brand glass for all ordinary purposes, although in certain instances where very high vacuum is required—particularly where the seals are to work under variation in temperature—it is recommended that a bead of sealing glass be introduced between the metal and glass. The sealing glass is made specially for the purpose by the manufacturers of Pyrex Brand glass and is sold by them under the name of Tungstil. They also produce graded glass seals, comprising glass of six or seven different compositions, by means of which Pyrex Brand tubing can be joined to soft glass.

Lumophor

This is a borosilicate glass of Continental origin by means of which it is claimed that the light emission of the rare gas mercury-vapour discharge is intensified in a part of the range as much as five times that of the ordinary luminous tube. The range of colours consists of:

(1) Daylight White.—For the illumination of workrooms, shop windows, operating theatres, photographic studios, etc. Its luminescence extends over all colours of the solar spectrum

from violet to red, whereby the greatest intensity lies in yellow and red. In this light all colours appear very natural. If a warmer light is desired a colour combination with numbers 8, 4 or 3 is recommended.

(2A). BLUE, CLEAR GLASS.—Is a transparent glass with blue luminescence.

(2B). BLUE TWO-PLY OPAL (with an outside layer of opal glass on the transparent Lumophor Glass).—An attractive and extremely pleasing shade of blue with light emission uniformly diffused over the entire tube.

(3). EGG YELLOW.—Gives a yellow light which, notwithstanding the change in colours from blue to yellow, is reasonably brilliant.

(4) CRIMSON.—For use where a red light is desired using an argon with mercury vapour filling.

(5A) BRIGHT GREEN, CLEAR GLASS.—Yields a bluish-green light.

(5B) BRIGHT GREEN, TWO-PLY OPAL (with an outside layer of opal glass on the transparent Lumophor Glass).—Light emitted is of a pastel green shade uniformly diffused over the tube.

(6) REDDISH-VIOLET.—An unusual colour used more for decorative effect or relief than for actual light emission.

(7) PINK.—For interior lighting where a warm effect is desired.

(8) IVORY WHITE.—Similar to No. 1, but giving a more yellowish light.

(9) MAY GREEN.—A yellow glass giving a fairly intense green with a blue discharge light.

(10) ICE-GREEN.—A pleasant alternative to the usual green tubes, being of a very pale shade.

(11) PURE WHITE.—Intended for interior or domestic lighting. Is much influenced by other light sources in its immediate vicinity and should, in common with all white luminous tubes, be used with discrimination.

(12) GREENISH-WHITE.—Used in conjunction with red tubing for pure white effects.

(13) YELLOWISH-WHITE.—Is a further alternative to Nos. 1, 8, 11 and 12, and gives a warm light suitable for public assembly rooms, exhibition halls, etc.

(14) LEMON YELLOW.—A bright yellow shaded slightly off to green.

(No. 627)—Gives a whitish green light of good brilliance.

(15) BRIGHT GREEN.—With an extremely high lumen per watt value.

Lumophor Glass Tubing is marketed in Great Britain by Lustray Products, Omnilucent Products Limited, of London.

FUSED SILICA OR QUARTZ

Silica—occurring as quartz rock, sandstone and other forms of SiO_2—is the commonest constituent of the earth's crust. It was first investigated materially by Gaudin who in 1839 communicated to the Academy of Science his experiments on the fusion of quartz, using an oxyhydrogen blowpipe which resulted in a transparent glassy mess with remarkable properties. In 1903 a furnace was set up at Wallsend-on-Tyne for the purpose of discovering the commercial possibilities of fused silica. This was actually the birth of the famous Thermal Syndicate. The late Dr. J. Frank Bottomley was in charge of the experiments and the electrical equipment was designed by Messrs. Merz & McLellan.

The first important exhibition of vitreous silica ware prepared under the Thermal Syndicate's patents was made at the Brussels Exhibition of 1910 and the material was given the name Vitreosil.

Vitreosil, which contains over 99·8% SiO_2, has an expansion of less than one-sixth of that of the best hard glass. The more important properties are:

(1) It is chemically unaffected by halogens and most acids.

(2) No fluxes or other foreign materials are introduced, the material being thoroughly uniform and homogeneous.

(3) Vitreosil, providing it is not devitrified, is not permeable to gases (apart from helium and hydrogen) under ordinary pressure, even at high temperatures.

(4) LOW EXPANSION AND CONSTANCY OF VOLUME.—The linear coefficient of expansion being $0{\cdot}54 \times 10^{-6}$ per degree Centigrade, and the thermal hysteresis $\left(\frac{\delta l}{8\,\Delta t}\right)^{-3\text{ to }-4} \times 10^{-9}$ when annealed.

(5) PROLONGED IGNITION at temperatures below the devitrification point, in the absence of reaction, produces no appreciable change of weight.

(6) HEAT RESISTANCE—the melting point is not well defined, but lies between 1700 and 1800° C. However, an appreciable softening of Vitreosil takes place at about 1500° C. It may be safely used at temperatures up to 1100° C.

(7) THERMAL CONDUCTIVITY of transparent Vitreosil is about 0·0035 calories per sec. per degree Centigrade per cm. per sq. cm.

(8) TRANSPARENCY—the transparent variety of Vitreosil fused quartz is the most transparent manufactured solid known. It transmits at high efficiency from 1850 Ångström units in the ultra-violet to upwards of 40,000 in the infra-red depending on the thickness and quality of the material. The transparency to visible light of a rod one metre long (the light being transmitted endwise) is 93%.

(9) ELECTRICAL CHARACTERISTICS—Resistance $4{\cdot}46 \times 10^9$ to $2{\cdot}69 \times 10^5$ at temperatures 277 to 877° C. Breakdown value at ordinary temperatures over 10 Kv. per mm. Power factor of the order of 0·1%.

GAS AND VAPOUR FILLINGS

In selecting gases and vapours for luminous tubes it is necessary to take into consideration the spectrum of the discharge, the ionisation voltage (see Table 6), the luminous efficiency and the possibility of reaction with the glass or electrodes.

TABLE 6

Resonance and Ionisation Potentials in Volts of Various Gases and Vapours

GAS	RESONANCE	IONISATION	VAPOUR	RESONANCE	IONISATION
Helium ..	*19·77	24·50	Mercury ..	*4·68	10·39
Xenon ..	18·39	12·08	Zinc ..	4·02	9·35
Neon ..	16·58	21·50	Cadmium ..	3·78	8·95
Argon ..	11·57	15·70	Magnesium	2·70	7·61
Krypton ..	9·98	13·94	Sodium ..	2·09	5·12
Nitrogen ..	8·10	16·70	Lithium ..	1·84	5·37

* Indicates that the potential applies to a metastable state.

It would appear that the ideal filling could be obtained by a mixture, but in practice this is only satisfactory with neon and helium or argon and mercury-vapour. In general, the characteristics of rare gases are not improved by mixing, since the main discharge tends to take place through the gas with the lowest ionisation potential, thus masking the light emission from any other gas.

Carbon Dioxide and Hydrogen

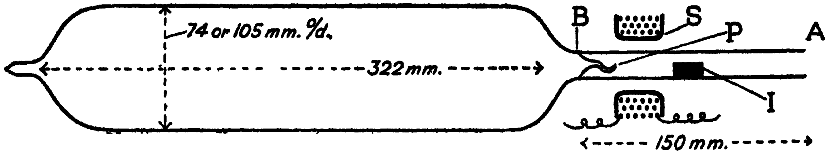
Ionised carbon dioxide, as used in Moore Tubes, although giving a good white light, has a poor luminous efficiency. In addition, it "cleans up" very rapidly and therefore requires some form of apparatus to ensure a constant supply.

The colour of a discharge in hydrogen (the lightest gas known) is pink, but again, the poor efficiency renders it unsuitable for most commercial lighting purposes.

Rare Gases

Helium is the second lightest gas and, used alone in a discharge tube, yields a yellowish light at a rather low luminous efficiency. Due to the comparatively high electrical resistance of ionised helium, the gas is little used alone.

Neon is about five times as heavy as helium and, as is well known, is widely used in the cold-cathode luminous tube industry. Most of the light of a neon-filled discharge tube is in the red-orange portion of the visible spectrum. The electrical resistance is about half that of helium and luminous efficiencies of as high as twelve lumens per watt have been obtained from a straightforward neon tube. It is advisable to use spectroscopically pure neon for luminous discharge tubes.



(British Oxygen Co. Ltd.)

FIG. 7.—B.O.C. GAS CYLINDER

Argon is also a popular gas for luminous tubing and, incidentally, for light sources in general. About twice as heavy as neon, this gas gives a pale blue discharge, although it is rarely used alone. Having a low electrical resistance, it is often used as a "carrier" in tubes containing mercury in order to sustain the discharge.

Krypton ionises with a light of pale lavender colour and is seldom used alone.

Xenon, the heaviest and rarest of the rare gases, possesses the lowest electrical resistance, the colour of the discharge being bright blue. It is not used alone and, on account of its extremely high cost, is seldom employed at all in luminous tube practice.

Rare gases are supplied at approximately atmospheric pressure in small soda glass bulbs of 200 c.c.'s capacity or in standard soda glass cylinders having a capacity of 1¼ or 1½ litres.

The dimensions and method of release of British Oxygen Company containers are indicated in Fig. 7. The cylinder is fused to the user's apparatus at *A*. After evacuation up to *B*, a current is passed through the solenoid *S* to cause the piece of iron, *I*, to strike smartly and break the thin-walled glass pip, *P*.

Mercury Vapour

The majority of blue and green luminous tubes contain liquid mercury which vapourises during operation of the tubes. Triple-distilled mercury should always be used for cold-cathode tubes and then, only in conjunction with a rare gas, as otherwise, the light emitted by the tubes would be erratic.

Discharges in the vapour and some of the rare gases mentioned above produce radiation in the invisible portion of the spectrum (e.g. ultra-violet), which, until recently, was lost insofar as light emission was concerned. The development of fluorescence has, however, provided a use for this radiation.

SEALING-IN WIRES

The principal characteristic of wire for sealing into glass is that it should have the same, or nearly the same, coefficient of expansion, since it is essential that the seal be vacuum-tight for luminous tubes; also, the electrical resistance must be reasonably low for most purposes.

For soft glass (e.g. soda-glass) platinum is the most obvious metal, but its high cost renders it prohibitive as a general rule. In addition, it is very easily broken off at the point where it enters the glass.

Copper-clad Nickel Alloy

For some purposes nickel or copper wire is found to provide a satisfactory seal into soft soda or lead glass, but in most luminous tube electrode pinches a composite wire known as Dumet wire is used.

A special wire of this type for use in luminous tubing has been evolved; this consists of a nickel-steel wire coated with copper which is, in turn, coated with a layer of fused borax.

The core is made from a crucible cast ingot of 42% nickel-steel, the ingot being smoothly ground and heat-treated in hydrogen to clean and properly prepare the alloy for cold drawing. A seamless copper tubing is put over the core but underneath it is placed a thin sheet of brass which acts as a flux or binder. After this, the rod is swaged, brazed and drawn through dies to the desired wire size. The finished wire is then treated with a borax oxide.

In order to make a perfect glass to metal seal, the glass must "wet" the wire. Any glass will wet and adhere to any clean, gas-free metal, provided that the metal is covered by a layer of oxide and the temperature is raised to the point where this oxide dissolves in the glass. However, by using copper-clad wire with correct annealing, seal strains in soda or lead glass can be reduced to a minimum. In a good seal, copper-clad wire appears golden in colour.

Some luminous tube manufacturers use a straight piece of copper-clad wire clamped direct to the electrode shell, thus serving three purposes: (1) to support the shell; (2) to make the seal; and (3) to make electrical connection with the cable. This practice is not recommended as it means that at least one important factor must be sacrificed. For example, in order to make a good seal the wire must have as small a diameter as is possible and it cannot have this if it must, at the same time, be of sufficient mechanical strength to support the electrode.

Undoubtedly the best seal-in wire consists of what is known as a three-piece weld. A good example of this is made by Glendale Vacuum Products Company of New York, and comprises:

(*a*) Svea metal wire, 0·025 inch diameter to support the electrode shell;

(*b*) photo-electrically inspected copper-clad wire, 0·016 inch diameter for sealing;

(*c*) Solid non-corroding alloy wire, 0·022 inch diameter which permits electrical contact and resists corrosion.

(*a*), (*b*) and (*c*) are welded together by automatic welding machines of the percussive condenser-discharge type, thus eliminating oxidisation.

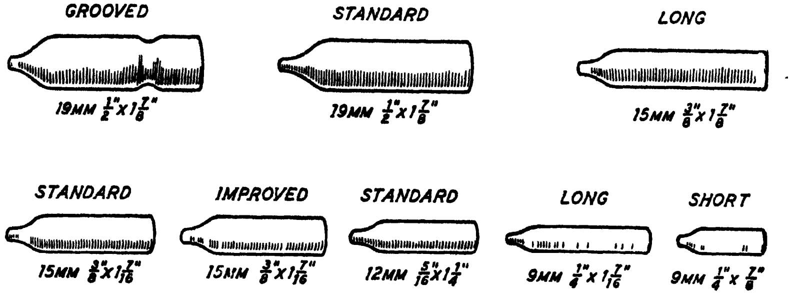
Tungsten

For tubes of Pyrex Brand glass, tungsten wire (having a coefficient of expansion of $4{\cdot}3 \times 10^{-6}$ per degree Centigrade) can be used for sealing-in. Its electrical specific resistance is 5 microhms per centimetre cube.

When heated to bright redness it becomes very brittle, and has a melting-point of about 3,370° C.

ELECTRODE SHELLS

Probably the first metal to be used for cold-cathode luminous tube electrode shells was copper, but its comparatively high disintegration or "sputter" factor led to a great deal of experimental work with different metals. A satisfactory metal known as Svea has been evolved, which is slag-free and reasonably immune from occluded gases.



(*Swedish Iron & Steel Corp*)

FIG. 8.—SVEA METAL ELECTRODE SHELLS

Svea electrode shells are manufactured by the Swedish Iron and Steel Corporation of New York City in the various shapes and sizes shown in Fig. 8. The result of this firm's tests on three metals is as follows:

TABLE 7

Characteristics of Three Electrode Metals Compared

	SVEA METAL	NICKEL	COPPER
1. PURITY AND UNIFORMITY ..	Highest (99·92)	Second	Third
2. MELTING POINT	1535° C.	1452	1083
3. STRUCTURE OF METAL ..	Dense	Porous	Very Porous
4. HEAT DISSIPATION	Oxidised Svea First	Third	Borated Cu Second
5. OCCLUDED GAS	Very Low	Medium High	Very High
6. MERCURY AMALGAMS ..	None Formed	Easily Formed	Easily Formed
7. SPUTTER FACTOR	4	75	180

Translated, these characteristics mean:

(1) PURITY AND UNIFORMITY.—The purity and uniformity of the metal used in electrodes are determining factors of safety in duplicating fine results on a production basis.

(2) High Melting Point.—A higher melting-point means less danger to the metal in case of over-heating during bombardment or processing.

(3) Structure of Metal.—Density of structure minimises both absorption of rare gases from the positive column during operation and release of fouling gases when tubing is not operating. Porous structure permits of easier treatment with emission compounds but at the sacrifice of life operating efficiency.

(4) Heat Dissipation.—Oxidised metal dissipates heat more rapidly than borated copper and much more rapidly than nickel. Bright Svea metal is slower than copper but slightly more rapid than plain nickel. Emission treatments keep all types cooler.

(5) Occluded Gas.—Surface degasification of the shell and careful bombardment will improve any metal electrode, but no such treatments can prevent the release of fouling gases occluded in the metal and released when sputtering takes place. That is why ordinary irons and even pure Swedish Irons failed to replace copper and nickel long ago. Svea metal has a much lower gas content than either copper or nickel or irons, steels and alloys. The reason is due to a special method whereby gas is almost completely removed.

(6) Mercury Amalgams.—Both nickel and copper readily form amalgams with mercury and this in time eats right into the body of the shell. The finest bombardment and surface treatment on clean and well-made copper or nickel electrodes would naturally give better results than poor bombardment on unclean or poorly made Svea metal electrodes.

The use of nickel cathodes in mercury rectifier tubes was necessarily discontinued because it was found that the mercury ate the nickel right out from under the cathode emission treatments in such tubes. Svea metal is now being extensively used for plates in the largest types of mercury rectifier tubes and is showing far superior results.

Cathodes for high pressure tubes which consist simply of a short coil of wire emission treated are not included in the foregoing.

(7) Sputter Factor.—The actual figures given in Table 7 are not claimed to be authoritative, since there seems to be some considerable variance in the publications of several experts, yet they do serve to indicate the difference between the three metals.

The rate of sputter is perhaps the most important single characteristic of an electrode metal for, in spite of all that has been written about cathode drop, this latter varies greatly with different gases, surface treatments and other factors.

Improvements in cathode drop are almost wholly up to the individual electrode manufacturer, since sputter factor—the rate at which the metal of the electrode shell is splashed onto the tubing, entrapping gas and finally destroying the effectiveness of the tubing—is dependent upon the metal used.

Star-shaped Electrodes

The electrode shells referred to previously are of the plain cylindrical type. A new star-shaped electrode has now been invented which, it is claimed, is superior to the cylindrical type from a sputter point of view, particularly where the lead-in wire come into contact with the glass.

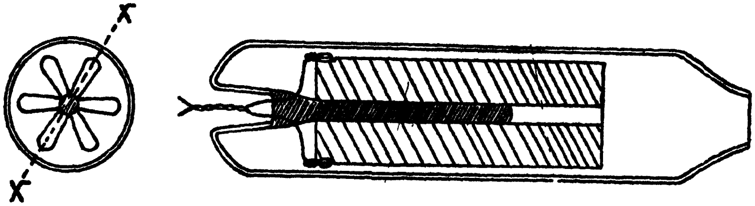


Fig. 9.—Star-shaped Electrode.
(Figure on right is a section through *X*—*X*)

The construction of the electrode is shown in Fig. 9, and it is manufactured in three sizes from Fischer Prima Glass and Krupp V2A Supra Steel.

(1) Large.—Made from a sheet of metal 18 × 6 centimetres in glass tubing of 40/44 millimetres diameter and constructed to stand up to operating currents of 80 milliamperes.

(2) Medium.—Made from a sheet of metal 10 × 6 centimetres in glass tubing of 32/34 millimetres diameter and standing up to operating currents of 40 milliamperes.

(3) Small.—From a sheet of metal 10 × 4·5 centimetres in glass tubing of 22/24 millimetres diameter and suitable for operating currents of up to 35 milliamperes.

Special lead-in wires, consisting of three sections, are used in his type of electrode. At the end of the electrode, which is made from metal of 0·2 millimetres thickness, two holes are bored diametrically opposite to take the platinum substitute wire 0·8 millimetres diameter, 30 millimetres long, leading to the pinch. In the pinch or the glass itself there is platinum-coated wire, 0·4 millimetres diameter, 5 millimetres long. Outside the tube is electrolytic copper 0·5 millimetres diameter, 85 millimetres long. The electrode shell is held by a glass rod passing through its axis.

Emission Coatings

Emission coatings proved so efficient in the radio valve industry that they have come into universal use for the valve filament and cathode sleeve. The luminous tube industry has been trying out many coatings and despite radically different operating conditions the coated electrode is rapidly gaining ground.

The increased use of emission coatings in low-pressure luminous tube electrodes can be divided into three main groups:

(*a*) The treatment of all types of electrodes to help to overcome the exceptional difficulties in producing strong white and gold lights of long life where helium is now used.

(*b*) The coating of electrodes made of high grade metals which gives the luminous tube maker much greater latitude in the pumping and bombarding of tubes, and which accordingly reduces the loss through overheating and increases the speed of production.

(*c*) The coating of electrodes made of metals which in bare form would not survive even a limited guaranteed life.

Although emission coatings substantially increase the life usefulness of many types of electrode and enable a small electrode to do the work of a larger uncoated electrode, they cannot change the inherent characteristics of the metal of which the electrode is made. They may temporarily mask bad features such as high sputter factor and high gas content due to porous metals, but the actual value over life periods has been much exaggerated and the search for an emission coating treatment of greater permanency is still world-wide.

Helium has a resistance to ionisation that requires emission coatings on the electrodes to cut down transformer cost and heating. Emission coatings are effective in this case when metallic barium, strontium, calcium or caesium are deposited on the electrodes and this is accomplished by chemically coating with carbonates, peroxides or similar compounds of the metal and then breaking them down to the metallic state by heating.

Heavy coatings cannot be used due to the risk of flaking during bombardment when they burn onto the tubing, causing star *cracks. Light coatings need care and control of the highest order* in application. Failure to completely reduce the chemical makes the coating ineffective, and overheating may allow the metal to be driven off during processing. Coatings using carbonates require great care to completely break down the coating and peroxides or similar compounds which break down at lower heats need care in avoiding driving off the metal.

Coated electrodes should not be allowed to come into contact with the atsmophere for if they are permitted to age in air the coating will be rendered of no value as an emission agent.

ELECTRODE INSULATORS

In considering any insulating material for use in an electronic device there are several points which should be taken into account, none of which must be overlooked. Among the more important insulators available are mica, lava, glass and the most common of all, space. Let us review briefly these various types, presenting the advantages, disadvantages, and treatment recommended for each.

Mica is probably the cheapest and lightest material and with proper treatment will give satisfactory service. It must not be overlooked that mica contains water vapour, but if fired in hydrogen or vacuum at sufficient temperature it is weakened as evidenced by a grey appearance rather than transparency and is easily split. Mica when hot is not as good an insulator as when cold, especially when very high voltages are used; which should be remembered during the bombarding process.

Lava, though possibly superior to mica, is more expensive and harder to mount in making up the electrode. It also offers the disadvantage of being extremely porous which necessitates special treatment as the lava does not become hot enough during pumping to thoroughly degas it. Lava is probably the best insulator of all when hot.

Glass may be used to advantage in some cases, taking into account the fact that hot soft glass is a conductor rather than an insulator.

Apart from any firing process, a very important factor insofar as insulation is concerned is cleanliness. It is not only the visible dirt that is liable to lead to trouble, but the invisible grease and finger prints due to excessive handling. A thorough wash with a suitable solvent such as clean alcohol is very advisable.

The open space between electrode and glass wall of the tubing is quite sufficient insulation in some cases.

Chapter 4

MANUFACTURING EQUIPMENT

IN its simplest form, a luminous tube manufacturing plant consists of a manifold system coupling up the vacuum pumps and gas cylinders, together with the necessary gauges and a bombarding transformer. A typical arrangement for low pressure tube processing is shown in Fig. 10.

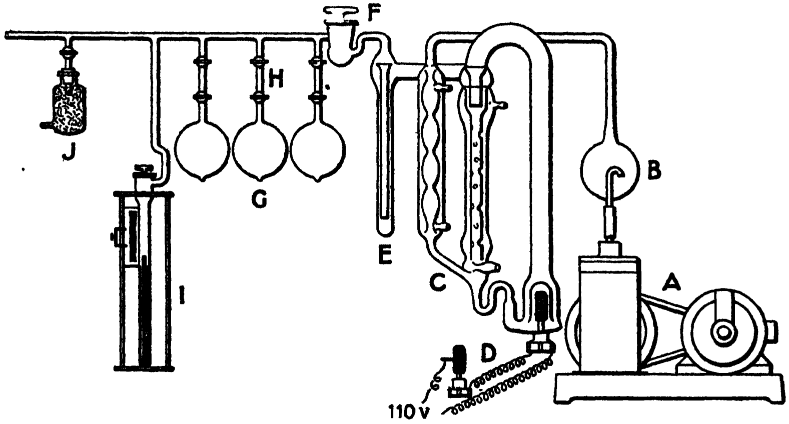


FIG. 10.—LOW PRESSURE LUMINOUS TUBE PLANT

A.	High Vacuum Pump and Motor.	*E.*	Trap.	*H.*	Gas Cocks.
B.	Trap.	*F.*	Main Stopcock.	*I.*	Gauge.
C.	Aspirator.	*G.*	Gas Cylinders.	*J.*	Calcium Chloride

As explained previously, a description of the many processes in the manufacture of the various types of luminous discharge tube would be of little value on account of the multitude of patents involved; furthermore, several volumes would be required to do justice to the subject. However, an account of the basic equipment employed should give a general idea of the operations entailed.

HIGH VACUUM PUMPS

The range of Edwards[1] pumps herein described are designed to cover almost all luminous tube requirements from small scale laboratory work to large industrial processes where the lowest possible pressures and highest pumping speeds are needed.

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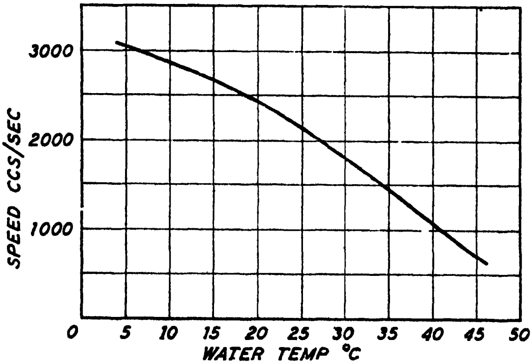
[1] Messrs. W. Edwards & Company (London), Ltd.

Diffusion Pumps

Mercury diffusion pumps provide the most satisfactory means of reaching very low pressures and even the smallest sizes have speeds at low pressures much greater than can be obtained by rotary pumps. Furthermore, they are extremely robust, have no moving parts to wear and can be dismantled for cleaning with a minimum of trouble. Since the diffusion principle can only be employed efficiently at pressures below 10^{-1} mm. Hg. approximately, these pumps must be used in conjunction with a suitable "backing" or "fore-vacuum" pump. This pump will normally be of the single stage oil-immersed type having an ultimate vacuum of 10^{-1} to 10^{-2} mm. Hg.

If the diffusion pump is to operate at maximum efficiency, it is essential that a "backing" pump shall be chosen with characteristics which are suitable for the proposed work. Where it is proposed to maintain a certain speed at some fixed pressure, the speed of the backing pump is calculated as follows: If the required diffusion pump speed is S_1 c.c.'s per second at a pressure of P_1 mm. of Hg. and P_2 is the rated backing pressure for the pump, then the backing pump must have a minimum speed of $\frac{S_1 \times P_1}{P_2}$ at a pressure of P_2 mm. This must not be confused with free air displacement which will generally be several times greater.



(*W. Edwards & Co.* [*London*], *Ltd.*)

FIG. 11.—EFFECT OF COOLING WATER ON SPEED OF DIFFUSION PUMP TYPE 3

All diffusion pumps need a certain heat input to vapourise the mercury and a flow of cooling liquid through the condensing jacket. Electric heating is most desirable, but for laboratory purposes the smaller types may be gas heated.

The speed of a diffusion pump is also influenced by the cooling water temperature and the curve in Fig. 11 shows the way in which the speed of the Type 3 varies with temperature. The speeds of all other models are affected in the same way.

Mercury Vapour Traps

Whilst the majority of operations and processes requiring high speed pumps are only concerned with the partial pressures of air or other gas, there are certain cases in which the total pressure of gas and vapour is of importance. As already it will be seen that the total pressure will be determined by the vapour pressure of the mercury, in some cases it will be necessary to trap the vapour which tends to diffuse back from the pump into the exhausted system.

This can be achieved by condensing the vapour on a cooled surface, the usual method at one time being to interpose a re-entrant glass trap between the pump and the tube and to immerse this in liquid air.

Such a trap, however, has considerable resistance and not only reduces the effective speed but prevents the direct connection of the pump to an all-metal system. A steel trap has therefore been developed by Messrs. Edwards & Company which can be bolted directly to the high vacuum connection of the pump. The internal construction of this is shown in Fig. 12.

The inner portion is filled with liquid air through the orifice at the side and as this inner container is surrounded by an evacuated space, the heat flow is restricted and the liquid air only boils off at a comparatively slow speed. Where the very lowest pressures are not essential, a mixture of solid

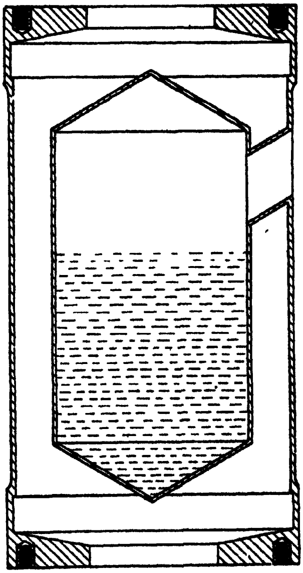


FIG. 12.—DIAGRAMMATIC VIEW MERCURY VAPOUR TRAP

CO_2 in acetone or trichlorethylene may be used. In this connection the following table of vapour pressures will be of interest.

TABLE 8

TEMPERATURE (DEG. C.)	VAPOUR PRESSURE OF MERCURY
20	$1{\cdot}1 \times 10^{-3}$ mm.
10	$4{\cdot}3 \times 10^{-4}$ mm.
0	$1{\cdot}6 \times 10^{-4}$ mm.
−76 (CO_2 trap)	$1{\cdot}0 \times 10^{-8}$ mm.
−184 (liquid air trap)	almost unmeasurable

Type 2 Diffusion Pump

The original Type 2 was made about the year 1930 to the design of Dr. G. W. C. Kaye, Superintendent of the Physics Department, National Physical Laboratory, but since then the experience gained both in laboratory and industrial applications has led to a number of modifications resulting in a pump combining the following desirable features: (*a*) High pumping speed is well maintained over a wide range of pressures; (*b*) Speed is comparatively insensitive to changes in backing pressure within a range easily reached by a single stage rotary oil-immersed pump; (*c*) the very lowest pressures are readily obtained, being well below 10^{-6} mm.

Other Types

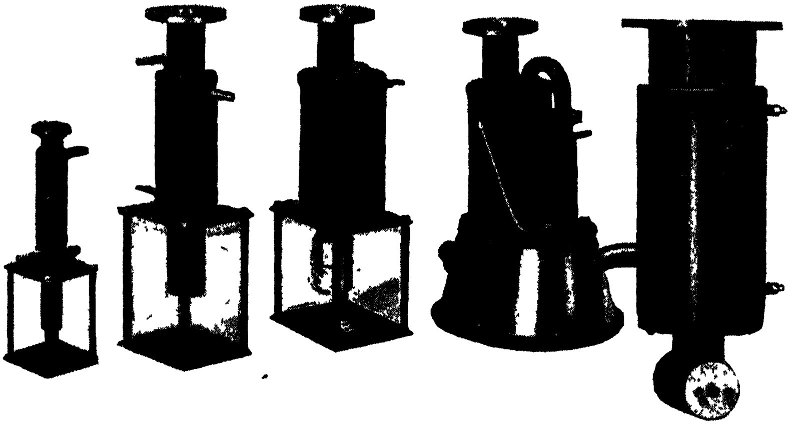
The characteristics of various Edwards' pumps are compared in the following Table:

TABLE 9

	TYPE NOS.			
	2	3	4	5
Speed, litres per sec.	6–8	2–3	20	20
Ult. Vacuum, mm. Hg.	10^{-6}	10^{-6}	10^{-6}	10^{-6}
Backing Pressure, mm. Hg.	0·5	0·5	0·1–0·25	1·5–2·0
Heat input, watts	300–500	150–200	250–500	450
Mercury charge, c.c.	50	20	50	70
Weight, lbs.	9	3	14	30

It will be noticed that Type 3 is a smaller edition of Type 2. The Type 4 pump, whilst similar in principle to Type 2, has a speed three times greater; it is particularly suitable for applications in which large volumes have to be exhausted from atmospheric down to a very low pressure. Type 5 is a combination of Type 4 backed with a Type 3. With this arrangement very low pressures can be maintained against considerable leakage or gas evolution without the need for an exceptionally large rotary backing pump. This combination has proved very effective for hot-cathode devices, in the manufacture of which it is essential to remove gas as fast as it is liberated in the bombarding process. The four types are illustrated in Fig. 13.

Type 120, also shown in Fig. 13, has the exceptional speed of 120 litres per second in standard form, and even higher speeds can be obtained by the use of special jet systems. The provision of backing for such high speeds presents special problems in the arrangement of suitable combinations of pumps.



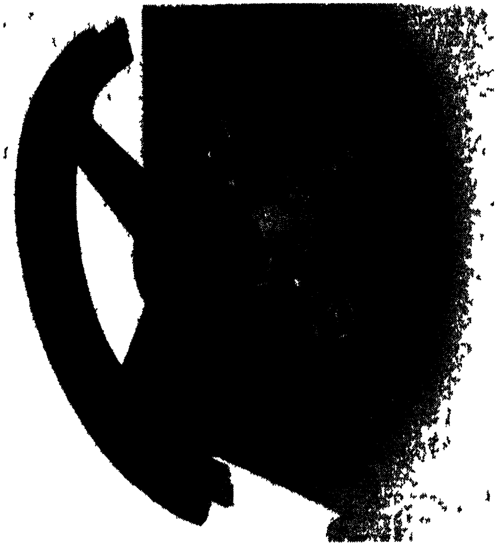
(*W. Edwards & Co.* [*London*] *Ltd.*)

Type 2 Type 3 Type 4 Type 120 with Type 4 as backing.

FIG. 13.—DIFFUSION PUMPS

Rotary Vacuum Pumps

The performance of a rotary pump is determined not only by the design but also by a suitable choice of materials. Six different steels are employed in the construction of Edwards' "Speedivac" Pumps, the main pump castings being made from a special iron alloy combining hardness and freedom from porosity with a remarkable resistance to corrosion. Special attention has been paid to lubrication and, as the ultimate vacuum is determined largely by the oil in the high vacuum stage, the two-stage pumps have been designed so that the oil is freed from gas during its passage from the main tank. Loss of oil as leakage from the shaft sealing gland and as vapour sprayed from the exhaust has been entirely eliminated; a special design of rotary seal (Fig. 14) being used on the shaft and a baffle cast in the lid for trapping spray.



(*W Edwards & Co [London], Ltd*)

FIG 14—ROTARY SEAL FOR VACUUM PUMP

The "Speedivac" pumps consist essentially of a rotor *A* (Fig. 15) having sliding blades *B*, held apart by springs *C*. The rotor is arranged to rotate within the stator *D* and is mounted out of centre so that the rotor and stator are in contact over a part of their diameters between the inlet port *E* and the outlet valve *F*. The whole assembly is mounted in an outer tank *H* and completely submerged in oil *G*. Air escapes from the outlet valve and leaves the tank by the connection *J*. A controlled amount of oil is allowed to reach the interior of the pump where it seals the contacting surfaces and also provides the necessary lubrication. As the rotor turns in the direction shown, the crescent-shaped space in communication with the inlet is isolated by the blades and the air trapped therein is carried round to the outlet valve and expelled. This operation continues until the pressure at the inlet is reduced to a small fraction of a millimetre (about 0·01 mm. Hg.) the limit being determined by the perfection of the fit of the various parts and the

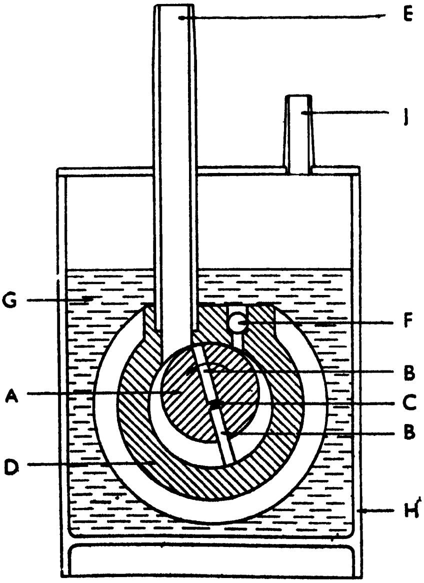


FIG. 15.—PRINCIPLE OF "SPEEDIVAC" PUMPS

sealing provided by the oil film. By using two similar sets connected in series and immersed in the same oil tank, extremely low pressures may be reached (0·00001 mm. Hg.).

"Speedivac" Types 1 and 3 are single-stage pumps and are suitable for backing diffusion pumps, whilst Type 2 is a two-stage pump for use where diffusion pumps are undesirable. In Tables 10 and 11 the characteristics of the three types are listed. Fig. 16 shows the external appearance.

TABLE 10

Vacuum and Displacement

Speedivac Type.	Vacuum mm. Hg.	Displacement.	
		Cu. ft./min.	litres/min.
1	0·005	2·6	75
2	0·00001	2·6	75
3	0·005	8·0	224

TABLE 11

Characteristics

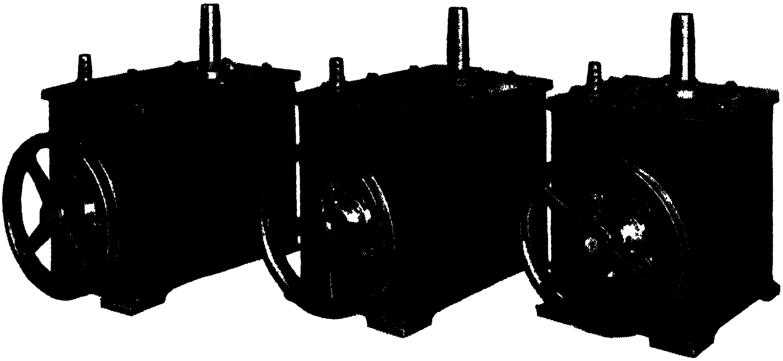
Speedivac Type.	Pump speed r.p.m.	Motor		Oil Charge gallons.	Overall length inches.
		H.P.	r.p.m.		
1	450–700	$\frac{1}{4}$ to $\frac{1}{3}$	1425	$1\frac{1}{4}$	24
2	450–700	$\frac{1}{4}$ to $\frac{1}{3}$	1425	$1\frac{1}{2}$	26
3	450–700	$\frac{1}{3}$ to $\frac{1}{2}$	1425	$1\frac{1}{2}$	26

Full advantage of the high performance of these pumps necessitates the use of short connecting tubes, preferably with a diameter equal to the inlet. All connections are of glass or solid drawn metal tubing, but short lengths of vacuum rubber may be used to connect the glass tubing, the rubber being lubricated with a suitable vacuum grease. The ends of the tube are smoothed and nearly touching inside the rubber sleeve.

When planning connections between the pump and vacuum system, provision should be made for a tap to admit air to the pump. If this tap is opened whenever the pump is stopped and shut immediately before starting, excess oil will be prevented from reaching the interior of the pump.

After the pump has been working for some time with the inlet closed, a metallic clicking may be heard. This is due to the steel valve striking its seating in the absence of the cushioning effect of the air passing through the pump, and is quite normal. It serves as a rough indication that a good vacuum is being reached.

Under no circumstances should these pumps be dismantled as the parts are adjusted with great care and it is extremely difficult to obtain the necessary accuracy. In normal use the pumps are not subject to wear owing to the film of oil between the moving parts.



(*W. Edwards & Co.* [*London*], *Ltd.*)

FIG. 16.—"SPEEDIVAC" PUMPS

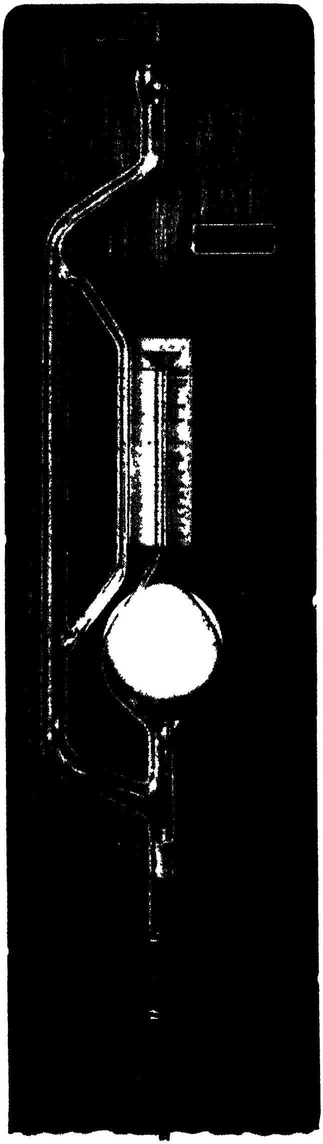
A small gauze filter in the inlet tube is designed to prevent foreign matter gaining access to the pump.

Maximum efficiency from these pumps can be obtained only if they are run at the specified speed and used with the correct oil. Failure to obtain the guaranteed pressure can then only be due to leaks in the system or the presence of vapours.

GAUGES

Of the various types of vacua measuring instruments available for luminous tube work, the McLeod Gauge is still among the most popular but, unfortunately, in its usual form it suffers from serious defects. The glass reservoir is fragile and the mercury easily spilled. When a rubber connecting tube is used, this in time, becomes perished, allowing air to enter both the gauge and the vacuum system; in addition, the rubber contaminates the mercury, thus causing the gauge to become dirty and give inaccurate readings.

A modified form of McLeod Gauge has been developed, in which all parts in contact with the mercury are of stainless metal with the exception of the gauge head which is readily removed for cleaning and replacement. The mercury reservoir is unspillable and unbreakable; there is nothing to deteriorate, whilst contamination and ingress of air are impossible. The glass head is joined to the vertical steel tube by a standard conical joint sealed with vacuum wax, and standard calibrated heads can be fitted quickly. The gauge is 5 feet 8 inches high and the baseboard 1 foot 3 inches by 1 foot; the head being shown in Fig. 17.



(*W. Edwards & Co.* [*London*], *Ltd.*)

FIG. 17.—A GAUGE HEAD

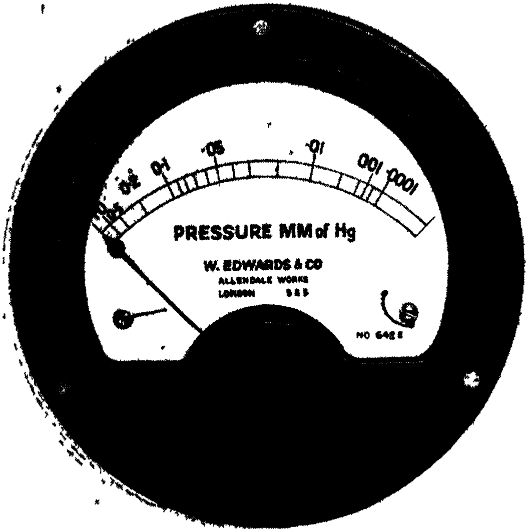
Direct Reading Gauge

Whilst the McLeod Gauge is still a reasonably satisfactory instrument for the accurate measurement of low gas pressures, there are two classes of work in which its use does not meet all requirements. Firstly, there are industrial processes in which it is necessary to indicate or even record rapid fluctuations of pressure. Secondly, it is sometimes more important to know the total pressure rather than the partial pressure of the true gases. Both these requirements are met by the Direct Reading Gauge which is a development of the Pirani type but with improved characteristics.

For laboratory use the electrical apparatus can be housed in one cabinet together with the indicating instrument, but for industrial purposes the latter may be mounted at some distance from the vacuum apparatus.

The standard instrument is for operation on A.C. mains between 200 and 250 volts, 50 cycles, and readings are independent of normal mains fluctuations. It is supplied with a 3½-inch dial indicator, shown in Fig. 18, teak cabinet and simple unprotected gauge tube.

For works use, the gauge should be protected by a metal case and the electrical apparatus may also be enclosed in metal. In this case the gauge is connected to the vacuum system by a standard flange, but for ordinary use a glass cone is used.



(*W. Edwards & Co* [*London*], *Ltd.*)

FIG. 18.—ELECTRICAL INDICATING INSTRUMENT FOR HIGHER VACUA

Manometers

The introduction of a special Apiezon oil having a negligible pressure (10^{-5} mm. at room temperature) has rendered possible the construction of this sensitive gauge (Fig. 19) which is ideal for the accurate reading of small pressures of gas admitted into a previously evacuated system.

(*W. Edwards & Co* [*London*], *Ltd.*)

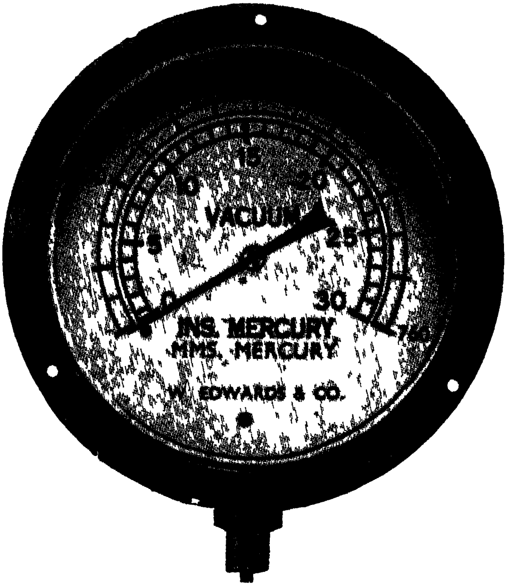
FIG. 19.—MANOMETER

The two limbs of the U-tube are joined by a stopcock which is normally in the open position. When the whole system is exhausted "hard", this cock is closed and, after setting the sliding scale at zero, the manometer is ready for reading.

Anti-parallax scales are fitted, and the gauge is supplied in two patterns, one for wall mounting and the other for bench work.

Dial (*Bourdon*) *Gauges*

This type of gauge is suitable for the approximate measurement of pressure between atmospheric and 1 or 2 centimetres. The dial—shown in Fig. 20—is graduated in both inches (0-30) on the inside in black, and millimetres (0-760) on the outside in red.



(*W Edwards & Co [London], Ltd*)

FIG. 20.—BOURDON VACUUM GAUGE

MOISTURE-FREEZING EQUIPMENT

It is essential in the manufacture of luminous tubing to produce a column of pure gas, for on this depends, to a great extent, the length of working life and the correct functioning and colour of the discharge. The removal of occluded gases is of course achieved by bombardment, but this does not prevent the removal of moisture.

At one time, phosphorus pentoxide (P_2O_5) was inserted between the tubing and the pump, thus acting as a dessicating agent for the exclusion of the moisture. This, however, was not entirely effective for it did not remove the last traces of moisture from the tubing nor did it prevent the moisture passing over and collecting in the oil of the rotary pump.

When the moisture and occluded gases were not removed completely during the evacuation and cleaning of the tube, it was often found necessary to run completed tubes for periods up to 24 hours at an over-potential to ensure freedom from these impurities. Such ageing runs at over-potential were a source of expense and trouble to the manufacturer; expense with respect to electrical energy and time required, and trouble in respect to space occupied.

A method of ensuring complete removal of moisture is now available, which consists of freezing the moisture during evacuation. In this method a small glass sump is inserted between the tube and the pump. The sump is then immersed in a bath filled with a Drikold cooled liquid or packed round with powdered Drikold.

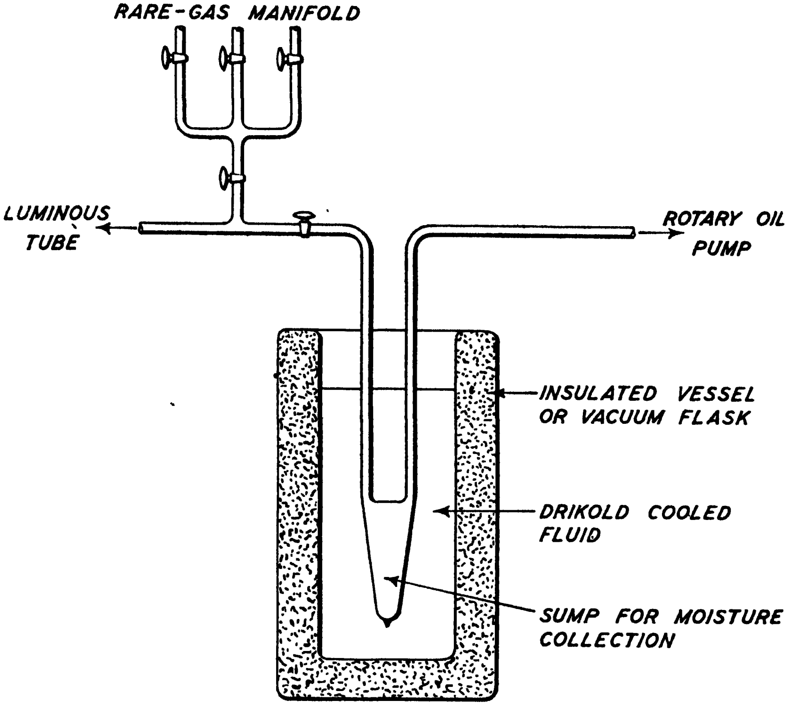


FIG. 21.—
APPARATUS FOR THE USE OF DRIKOLD IN THE MANUFACTURE OF LUMINOUS TUBES

Where liquid is used, and this is preferable to ensure a good heat transfer, any liquid such as white spirit, methylated spirit, benzine or acetone, which does not freeze at the temperature of Drikold can be used.

The moisture in the sump is in the solid state and must be removed when a quantity has collected. The simplest way of doing this is to scrap the sump and insert a new one. Alternatively, the bottom of the sump can be broken off, the ice removed and the bottom again fused together.

The advantages of this method are as follows:

(1) Moisture is effectively removed from the tube and collected as ice in the sump.

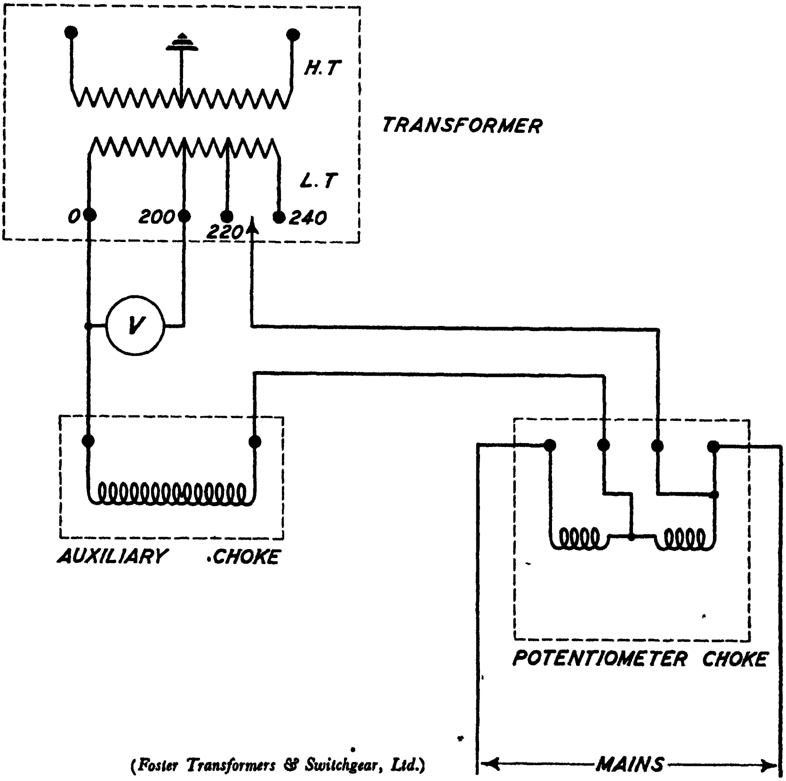
(2) The moisture cannot pass into the oil in the pump.

(3) Reduces the time required to evacuate and clean the tube.

(4) Owing to the very low temperature of the gas after passing through the sump, the pump does not heat up to such an extent as it would otherwise.

(5) No ageing runs are necessary.

A typical apparatus of this kind is shown in Fig. 21.



(*Foster Transformers & Switchgear, Ltd.*)

FIG. 22.—DIAGRAM OF CONNECTIONS FOR NEON TUBE BOMBARDER

BOMBARDING TRANSFORMER

Fig. 22 is a diagram of connections of a transformer suitable for bombarding cold-cathode luminous tubes. The transformer, which is rated for a short time output of 7 K.V.A., is oil-cooled and fitted in a steel tank. The secondary is 15,000 volts with mid-point earthed; the usual primary terminal voltages are 200, 220 and 240.

The control on the primary side is arranged so that a varying voltage can be supplied to the main transformer primary winding. This voltage can be adjusted for any value between zero and full pressure, with a corresponding variation in the secondary pressure of the main transformer.

There are several different types of control, but most bombarding sets are fitted with a potentiometer choke consisting of two choke coils in series connected across the mains, the primary of the main transformer being supplied from the terminals of one choke coil.

The chokes have movable cores so disposed that when one is inserted fully in its coil the other is withdrawn. This arrangement acts as a sort of variable auto-transformer—the voltage across the primary of the main transformer being highest when the core is fully inserted—from the terminals of which the main transformer is supplied.

Operation of the controller is by means of a large hand-wheel, so that the voltage can be raised from zero to maximum by one complete turn of the wheel. In some cases an additional choke is used.

Chapter 5

LOW-PRESSURE TUBES

The best-known type of low pressure tube is of the form used in neon advertising signs. It consists of a soda-glass tube exhausted and filled with rare gas at a pressure of about 12 millimetres of mercury and fitted with a cylindrical metal electrode at each end. The usual construction is shown in Fig. 23.

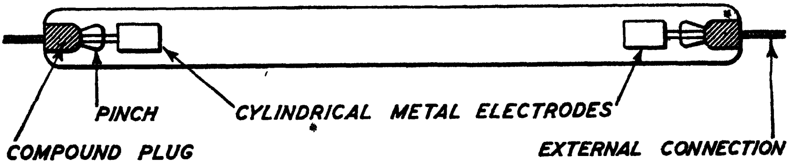


Fig. 23.—"Neon" Tube

If the tube is operated from high voltage direct current with a ballast resistance in series, the potential drop along the discharge will be similar to Fig. 24, being fairly steady through the positive column, smaller near the anode and comparatively large in the region of the cathode. It is found that the potential drop through the positive column varies inversely as the diameter and decreases

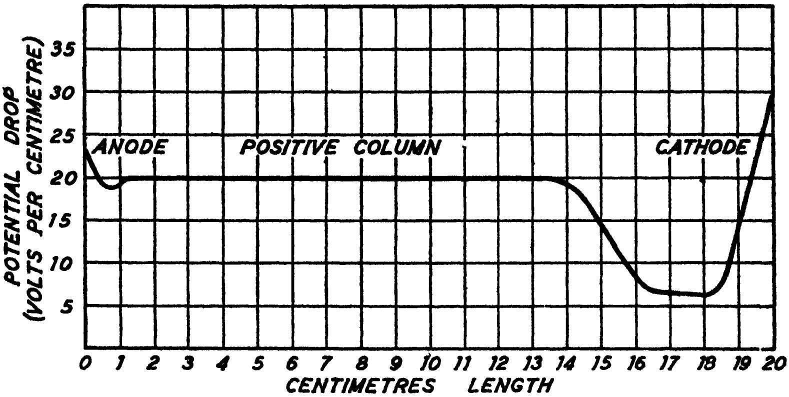


Fig. 24.—Potential Gradient for Low-Pressure Tube on D.C.

with increase of current. The relatively large drop near the cathode causes the "sputtering" which determines the life of the tube.

NEON TEST TUBES

Small neon tubes of the electrodeless type are extremely sensitive to minute currents and glow with a bright red-orange colour when excited by an alternating electrostatic or radio-frequency field.

The tubes, from 1¼ inches to 3 inches long (see Fig. 25), are constructed from clear glass tubing with metallic caps on each end and are filled with a highly purified neon gas.

Principle

The principle of operation is based on a condenser action between the metallic caps on each end of the tube. The action and current flow follows somewhat similar laws applying to capacitators with the neon gas acting as a conductor between the metallic end caps. The current required to operate this type of tube is almost negligible; in normal practice the current drain will rarely exceed three or four microamperes.

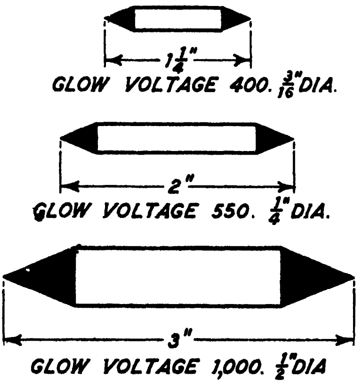


FIG. 25.—NEON TEST TUBES.

However, the current-light ratio efficiency is very high, particularly when the frequency is above 5,000 cycles. Above this frequency, complete deionisation of the neon gas does not occur between cycles. Roughly speaking, the current transmitted varies directly with the frequency and with the square of the applied voltage.

This type of tube has many desirable advantages in some applications. The effective impedance or resistance is very high. This factor is important because it means that the tube may be used in low current circuits without causing an appreciable change in the normal operation of the circuit.

Internal Electrode Type

Internal electrode glow tubes, as shown in Fig. 26, have versatile uses in testing work. They are generally larger than the electrodeless type, perhaps about 9 inches from cap to cap. This type is really a current measuring tube; the length of the glow along the electrode being a measure of the current through the tube. For this reason it may not only be used for direct current measurements, but also for indicating the relative current in radio-frequency circuits.

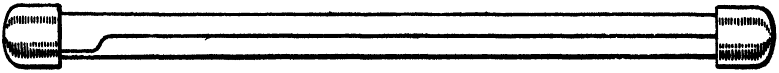


FIG. 26.—INTERNAL ELECTRODE GLOW TUBE

The intensity of oscillations from the radio-frequency generator will cause a bright glow to creep up within the tube along the electrode. The current in the tube must be limited on direct discharge work to 10 milliamperes or less. In direct current circuits the long central electrode should always be negative.

Spark Plug Tester

In spark plug testing the relative glow is used as an indication of ignition voltage strength. A bright flash indicates a good plug, a dim flash a dirty plug, no flash a " shorted " plug.

Coil Testers

For testing the output of ignition coils or other high tension coils, the electrodeless tube is generally used in conjunction with a calibrated spark gap. This test indicates both voltage output and the insulation of ignition coils.

The points of the gap are placed together and spaced until the test tubes begin to flicker. This point indicates the relative strength of the coil output. The spark gap may be controlled with a dial with markings: "poor; good; excellent".

Screwdrivers

Efficient universal high tension testers are easily made by inserting a small electrodeless test lamp inside the handle of the screwdriver. The handle should be made of transparent phenolic or similar material. A standard screwdriver of this construction may be purchased on the open market.

Insulation Tests

The relative glow intensity of an electrodeless tube is used as a measure of the insulation efficiency of the high tension cable. A very dim or no flash shows a perfect cable, a bright flash a leaky one.

Radio-Frequency Pilot Lamp

Small electrodeless tubes make excellent indicators of live radio-frequency circuits when used without any direct connections to the circuit. The tubes are placed in the radio-frequency field of the generator. More intensity is obtained by earthing one end of the tube.

Diathermy

The test probe is used to indicate the radiations surrounding the patient whilst taking diathermy treatments, thus enabling the doctor to know when the power is on, or of dangerous proportions. As a general rule, power insufficient to ignite the probe is not great enough to inflict burns.

Electrode tubes, made up into pocket-size probes with nickel-plated end caps are very handy for test work around radio-frequency equipment.

Transmitter Tuning

Internal electrode tubes, as mentioned previously, are sensitive current measuring devices, and are particularly suitable for tuning radio transmitters and radio-frequency oscillators. Any change in current is immediately noticed by a change in length of the electrode glow.

This efficient method of tuning affords an indication of output, point of perfect neutralisation, radio-frequency tracing, modulation percentage and overall performance.

Other Applications

Small neon tubes of the types described above have been successfully developed for:

Static indicators.
Novelties—illuminated glasses, etc.
High tension safety devices.
Ignition pilot lamps.
Spark-gap pilot lamps.

THE DISCHARGE TUBE STROBOSCOPE

The stroboscope, so far as engineers are concerned, may be defined as an apparatus used for intermittent viewing of rotating machinery. The earliest type consisted of a rotating slotted disc or shutter, the speed of viewing being dependent on the number of slots and the speed of rotation. Intermittent illumination can, however, be obtained from a flashing source of light, and this is the principle of the discharge tube stroboscope. Ordinary incandescent lamps fed from A.C. mains make inefficient types of stroboscope.

Light Source

In the apparatus an inverted U-shaped discharge lamp is used; usually of 11 millimetres diameter and 20 centimetres long. When an intense source of small area is necessary, the tube may be arranged end on. The tube can be clamped to an ordinary retort stand.

Tubes can be filled with neon, argon, helium or a combination of mercury with any one of the three.

Undoubtedly the best arrangement is a self-contained unit consisting of an aluminium case containing a specially wound transformer of rigid construction into which can be plugged instantaneously any of the interchangeable discharge tubes. The unit is generally standardised for A.C. voltage, but the same transformer may be operated on interrupted D.C. for stroboscopic work, the voltage necessary depending mainly upon the frequency of interruption.

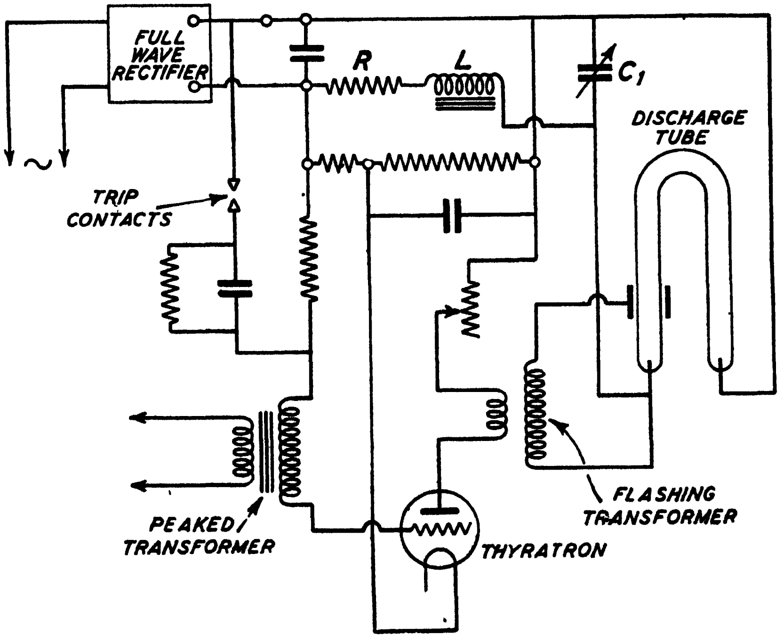


Fig. 27.—Discharge Tube Stroboscope

Control Equipment

The discharge tube in the circuit illustrated in Fig. 27 is, of course, operated by the flashing transformer controlled by a thyratron, the grid of which is negative until the trip contacts are shorted, removing the bias. Then the thyratron discharges through the flashing transformer and produces a high voltage surge through the discharge tube. This ionises the gas filling, thereby causing a flash of light.

A variable condenser C_1, a resistance R, and an inductance L are included in the circuit for timing purposes. Naturally, the triggering point depends on the thyratron control of the flashing transformer, C_1, R and L being necessary to build up the voltage to the required discharge point in any predetermined period.

The thyratron is triggered through the peaked transformer, which is arranged to produce one discharge every cycle; although the trip contacts can be actuated by a rotary drive mechanism from the machine under test.

Applications

Stroboscopes are used for the investigation of dynamos under operating conditions. Excessive flashing can be easily traced and commutator defects and loose parts quickly detected. Instantaneous photographs of rotating machinery can be taken with an ordinary camera by the light of the discharge tube.

Baird television receivers were to a certain extent a development of the stroboscope in that the light from the neon lamp was scanned by a slotted disc and the original picture built up in this way.

SODIUM DISCHARGE LAMPS

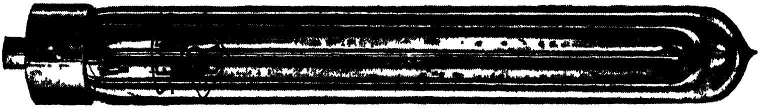
Although it was known for some years that the sodium discharge was of extremely high intensity, it was only the invention, by Pirani, of a special glass which was resistant to sodium vapour that made possible the development of the sodium discharge lamp. Ordinary quartz and hard glasses are violently attacked by the sodium, which vaporises at about 300° C.

The now familiar monochromatic yellow light emitted by sodium lamps is only suitable for special situations, but since it is radiated at wavelengths to which the human eye is particularly sensitive, the luminous efficiency is of a very high order—in some cases more than 70 lumens per watt.

The lamp consists, as shown in Fig. 28, of a U-tube of two-ply glass containing metallic sodium and neon at low pressure, the whole being enclosed in a vacuum jacket for heat conservation.

The inner ply of the U-tube is of special low silica-content glass resistant to the hot sodium.

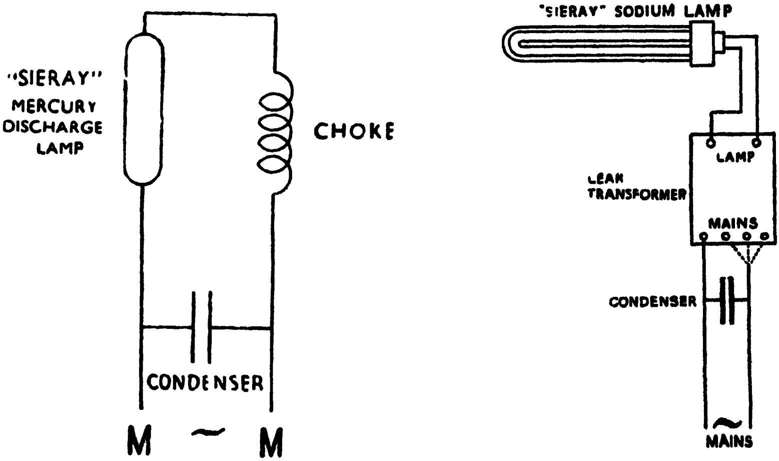
As with mercury lamps, the discharge strikes up through the inert gas, but this time by the application of about 400 volts across the tube through a leak transformer. Gradually, the low pressure discharge heats up the tube and the sodium begins to vaporise, causing the colour of the discharge to change from neon red to sodium yellow. Full light output is reached after 10 to 15 minutes.



(Siemens Electric Lamps & Supplies, Ltd.)

FIG. 28.—SODIUM LAMP

Leak transformers for this purpose are designed to have just sufficient "no load" secondary voltage to cause the arc to strike.



(Siemens Electric Lamps & Supplies, Ltd.)

FIG. 29.—CONNECTION OF "SIERAY" LAMPS

After starting, the leak transformers exercise the necessary control over the lamp circuits in the same way as the chokes in the mercury discharge lamp circuits. Power factor rectification is, of course, necessary.

Connections for Siemens "Sieray" mercury and sodium lamps are shown in Fig. 29.

The rating, performance and efficiency of modern sodium lamps operated on 230-volt supplies are tabulated below:

TABLE 12

RATING OF LAMP (Watts)	LOSS IN TRANSFORMER (Watts)	NOM. INITIAL LIGHT OUTPUT (Lumens)	NOM. INITIAL EFFICIENCY (Lumens/Watts)	GUARANTEED HOURS
45	22	2,500	55·5	3,000
60	22	3,900	65·0	3,000
85	22	6,100	71·5	3,000
140	27	10,000	71·5	3,000

LOW PRESSURE U.V. LAMPS

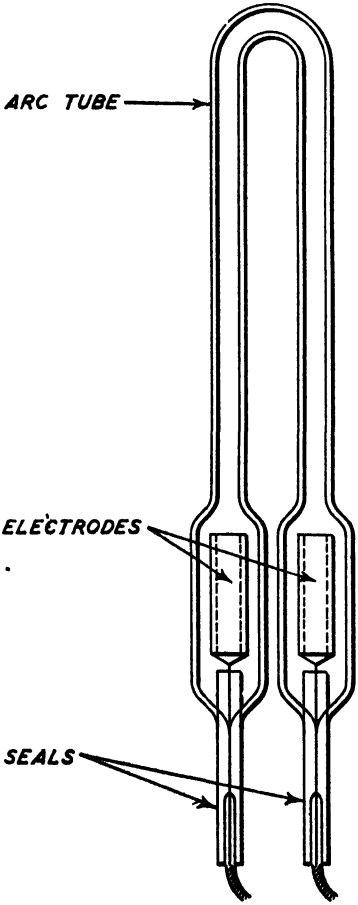


Fig. 30.—Low-Pressure U.V. Lamp

As a source of ultra-violet radiation for operation on alternating current, the gas discharge tube has many advantages over the rectifier type of lamp. It consists essentially of a fused quartz tube with a metal electrode at each end, and containing mercury together with a small quantity of inert gas—neon or argon.

Fig. 30 shows a low pressure gaseous discharge tube for use as an ultra-violet source. Current is supplied to the electrodes from a step-up transformer provided with a leakage path in its magnetic circuit.

The lamp starts up as an ordinary cold cathode neon tube, but as it gradually warms up the mercury vaporises until, finally, the discharge takes place through mercury vapour alone (since mercury vapour ionises at a lower potential than the inert gases).

It is obvious that the applied voltage must be sufficient, on starting, to ionise the gas, but can be considerably reduced when the resistance falls owing to the lower ionisation potential of mercury vapour. This automatic regulation is provided by the magnetic leakage in the transformer, which diverts more and more of the magnetic flux from the secondary as the current increases. Thus the output voltage of the transformer falls off rapidly as the load increases.

Low pressure U.V. Lamps operate at from 20 to 150 milliamperes, so that the temperature of the tube is never high enough to burn the skin with contact.

MERCURY ARC U.V. LAMPS

Quartz mercury arc lamps have for some time been definitely established as a convenient and reliable source of the ultra-violet radiation invaluable for therapeutic and photo biological purposes as well as for rectification and fluorescent analysis.

If a quantity of mercury sealed in an evacuated glass tube is arranged to carry current, a mercury arc is created whenever the pool is divided. This is the fundamental principle of the mercury arc lamp.

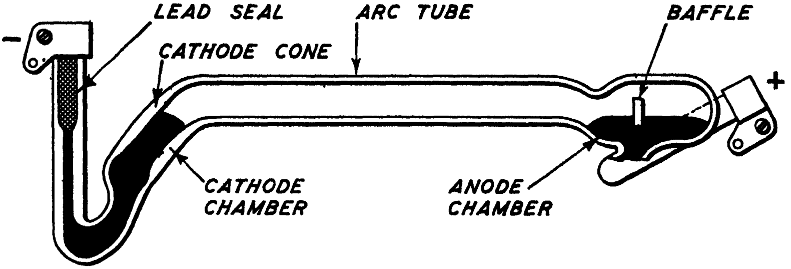


Fig. 31.—D.C. Vacuum Lamp

D.C. Vacuum Lamp

Fig. 31 is a section of the D.C. Vacuum Lamp. It consists essentially of an evacuated quartz tube containing two pools of mercury, the anode (positive) chamber being constricted so as to allow mercury contained therein to flow towards the cathode when the tube is tilted, and thus strike the arc; the tilting gear is not shown in the diagram. No mercury can be displaced from the cathode chamber on account of its position relative to the axis of the tube. The stricture or cathode cone prevents the lamp from flickering due to movement of the cathode spot.

Although the tube is nominally evacuated, the heat produced on striking the arc vaporises some of the mercury which is subsequently ionised, and the brilliant "cathode spot" is established. As the mercury pools recede, further ionisation is promoted and the arc current will tend to increase indefinitely. Thus, the arc is electrically unstable and requires a series resistance.

Since the anode receives the kinetic energy of the electrons, it will tend to run hotter than the cathode and there would be a tendency for mercury to be transferred from anode to cathode. This is prevented by the conical shape of the cathode opening; any excess mercury at the cathode reduces the area exposed, causing excessive heat which boils off the surplus mercury. It is therefore particularly important in this type of lamp that the polarity should never be reversed.

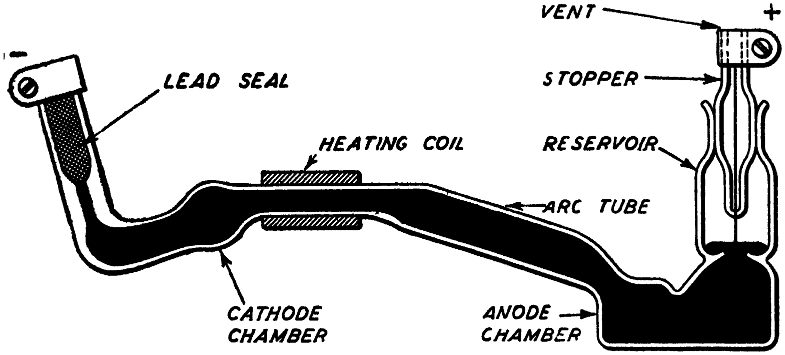


Fig. 32.—D.C. Atmospheric Lapm

D.C. Atmospheric Lamp

No tilting is required to strike the arc in the "atmospheric" type of lamp, so-called because the anode chamber is exposed to the atmosphere. A section of the lamp is shown in Fig. 32. There is a heating coil surrounding the cathode cone, which boils the mercury at that particular spot until a gap is created, thus causing an arc.

The vapour pressure then increases, pushing the mercury into the anode chamber until finally the arc fills the tube.

In common with the vacuum lamp, it is necessary to connect a resistance in series with the atmospheric lamp for stabilising purposes. It is the value of this "ballast" resistance that determines the arc current. Any increase in current through the tube results in a greater voltage drop across the resistance, rendering the anode less positive in relation to the cathode.

A 15-millimetre diameter atmospheric lamp on a 230-volt D.C. supply will have an arc about 4½ inches long. In conjunction with a ballast resistance of 33 ohms, the lamp would have a striking current of 6 amperes and an operating current of 2·5 amperes.

Cooling fins are usually fitted around the anode and cathode chambers of both vacuum and atmospheric lamps.

A.C. Rectifier Lamps

Since, as we have seen, the polarity cannot be reversed in the direct current lamps, it is obvious that they are unsuitable for alternating current. In any case, the necessity for continually re-striking the arc would prohibit the use of these lamps on A.C. in their present form.

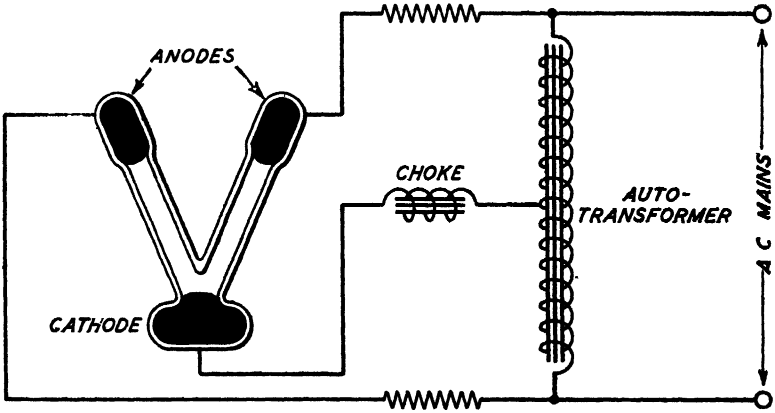


Fig. 33.—A.C. Rectifier Lamp

Fig. 33 shows an A.C. circuit for operating a modified form of mercury arc lamp with two anodes, to each of which is connected a stabilising resistance. One anode functions on the positive and the other on the negative half-cycle of the voltage wave. The anodes are connected one to each end of an auto-transformer, the centre tapping of which is taken to the cathode.

Obviously, at any instant during each cycle, there will be one anode positive with respect to the cathode, except at the transition stage at which both anodes will be at zero potential. A 0·2 henry choke-coil is therefore connected in the cathode lead so that the current will be inductively maintained by reason of the collapse of the magnetic flux when the arc current approaches zero: the choke also helps to stabilise the arc.

Since the current in the cathode is uni-directional, this type of lamp is called a "rectifier", and is used extensively for rectification. In this case, however, the auto-transformer is not essential, but a choke of larger inductance is used, the arc being maintained by the inductive e.m.f.

Cooper-Hewitt Lamp

The classical form of A.C. Rectifier Lamp is the Cooper-Hewitt Type, shown in Fig. 34. There are three operating electrodes together with a supplementary starting ring; the cathode, of course, being a pool of mercury.

On an average, the light efficiency of Cooper-Hewitt Lamps is from 14 to 15 lumens per watt, which is maintained for about 1,000 hours of operation.

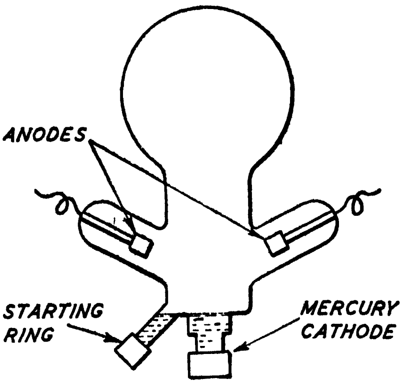


Fig. 34.—Cooper-Hewitt Lamp

Low-Pressure Hot-Cathode Tube

This type of tube is particularly suitable for colour floodlighting. It is supplied in the form of a glass tube fitted at each end with a two-pin cap, and is usually rated at 200 watts; the luminous column being about 24 inches long.

The light produced in the above lamp is red, and is much more intense than that obtained from cold-cathode tubes.

Principle

In order to minimise the considerable voltage absorbed in the cathode drop of low pressure tubes, the electrodes are of the hot-

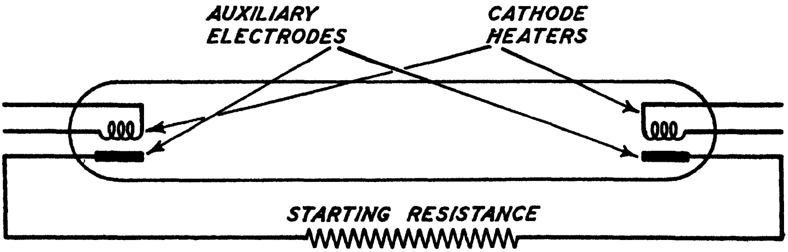
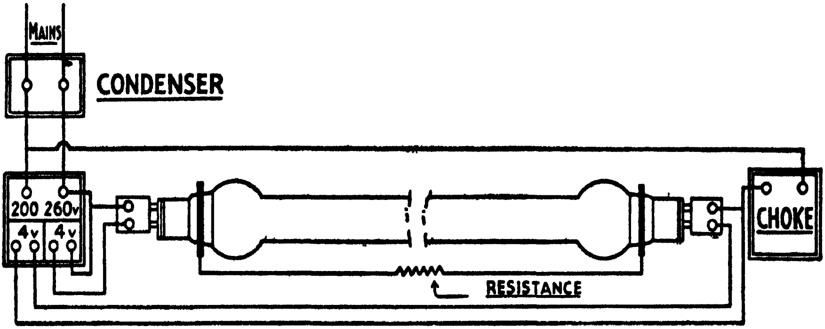


Fig. 35.—Principle of Low-Pressure Hot-Cathode Tube

cathode type. The difficulty in initially striking the discharge is overcome by using auxiliary electrodes as shown in Fig. 35. Once it is started, the high resistance connected across the auxiliary electrodes automatically cuts out the auxiliary circuit and the discharge is built up across the main electrodes.

Control Circuit

Fig. 36 depicts a tube with its associated circuit, the current being controlled by a choke coil. The filament heaters are fed from two separate 4-volt secondaries of a step-down transformer, the primary of which is tapped in 5-volt steps from 200 to 260 volts.



(*Siemens Electric Lamps & Supplies, Ltd.*)

FIG. 36.—DIAGRAM OF CONNECTIONS FOR LOW-PRESSURE HOT-CATHODE TUBE

Since these tubes operate at comparatively low pressure, there is virtually no delay in building up to full luminous output after switching on, whilst the lamps strike up at once when hot. It is necessary to incorporate a condenser of 25 microfarad capacity for power factor correction of the circuit.

Chapter 6

HIGHER PRESSURE TUBES

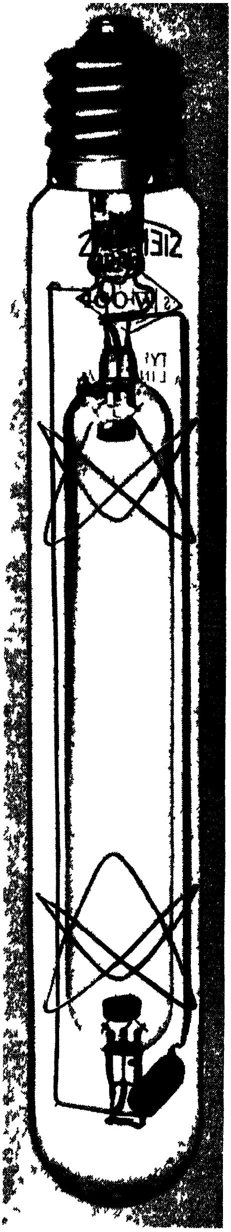
In 1930 it was realised that the luminous efficiency and colour rendering of mercury discharge tubes improved with increase of vapour pressure, and experiments were commenced with a view to development of the tubes as sources of light. The medium-pressure lamp, utilising a hard glass tube and self-heating oxide-coated cathodes, was the direct result of this research.

Medium Pressure Lamp

The lamp (shown in Fig. 37) consists of an inner tube of hard glass, which contains the actual discharge, surrounded by an outer jacket of ordinary soda-glass. The space between the two is gas-filled to minimise loss of heat. At each end of the inner tube, which contains a low pressure filling of inert gas together with a small quantity of liquid mercury, is an electrode consisting of a coil of thick tungsten wire surrounding a core of electron-emitting alkaline earth oxide. These are kept at the necessary high temperature by ionic bombardment, thus dispensing with the need for a separate heating circuit.

A choke-coil is necessary in the external circuit for stabilising the discharge, and a power factor correction condenser is usually included.

After first switching on, the lamp starts across auxiliary electrodes with a cold-cathode low pressure discharge through the neon or argon filling. The heat developed



(*Siemens Electric Lamps & Supplies, Ltd.*)

FIG 37. — MEDIUM PRESSURE HOT CATHODE TUBE (MERCURY)

vaporises the mercury, resulting in an increase in the pressure until the discharge is induced between the main electrodes. When the main discharge is in operation, its lower resistance automatically cuts out the auxiliary electrodes.

A short interval (5 or 6 minutes) elapses after switching on before the maximum efficiency is reached, due to the time-lag necessary for the mercury in the tube to become fully vaporised. If the lamp is switched off and then immediately switched on again it will not re-light at once, but will do so after a few minutes. This is owing to the fact that the lamp needs to cool down somewhat, and thus reduce the high vapour pressure and consequently the striking potential before the discharge can pass.

The light output of the discharge in the initial stages is low, but this rises rapidly with increase in temperature the discharge eventually forming a cord of intense light in a straight line between the electrodes.

Normally, the lamp can only be burned in the vertical position, as if it were to be operated horizontally, convection currents inside the inner tube would cause the arc to bow upwards with destructive consequences to the tube. Since the arc is metallic (mercury) the effect of these convection currents can be neutralised by means of an electro-magnetic device.

Special lamps or magnetic deflectors are obtainable should it be necessary for the lamps to be burnt horizontally.

High Pressure Lamp

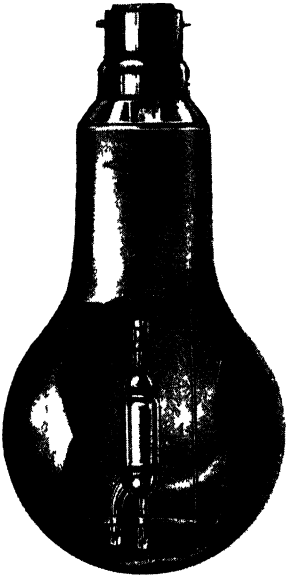
By using a special grade of quartz for the inner tubes and modifying the construction of the lamps, it is now possible to obtain considerably higher pressures.

Fig. 38 shows the high pressure type of lamp, from which it can be seen that the arc light source is very short and concentrated. This concentration of the light source introduces a number of advantages: (1) The time taken for the lamp to reach full luminous output is considerably shortened; (2) The cooling time after switching off, and consequently the lapse of time before restriking can take place, are reduced; (3) The lamps can be used effectively in standard types of fittings designed for gas-filled lamps. In addition, high pressure lamps embodying this principle can be burned in any position.

In general, the operation of the high pressure lamp is similar to that of the medium-pressure lamp, the connection in the external circuit of tapped choke coils for current limiting purposes and condensers for power factor correction being normally required.

The high working pressure of the lamps, however, leads to their emitting light with a spectrum of a more continuous nature than that of medium pressure lamps, and there is a very slight proportion of red rays present.

To reduce glare the lamps are made with pearl bulbs (Fig. 38). As the bulbs used are the same as the 200-watt and 150-watt General Service lamps, they are fitted with 3-pin B.C. lampholders to avoid their insertion into an unchoked circuit.



(*Siemens Electric Lamps & Supplies, Ltd.*)

FIG. 38.—HIGH PRESSURE HOT CATHODE TUBE (MERCURY)

Characteristics

The rating, performance and efficiency of modern mercury discharge lamps operated on 230-volt supplies is tabulated below:

TABLE 13

	RATING OF LAMP (Watts)	LOSS IN CHOKE (Watts)	NOM. INITIAL LIGHT OUTPUT (Lumens)	NOM. INITIAL EFFICIENCY (Lumens/Watts)	GUARANTEED HRS.
HIGH-PRESSURE	80	10	3,040	38	2,500
	125	12	5,250	42	2,500
MEDIUM-PRESSURE	250	15	9,000	36	3,000
	400	20	18,000	45	3,000

Stroboscopic Effect

When an ordinary gas-filled tungsten filament lamp is operated on A.C. mains, the filament naturally becomes cooler and hotter according to the cyclic variation of the supply. But, since the tungsten spiral has sufficient mass to retain a considerable proportion of the heat, the effect of the cyclic variation on the light output is unnoticeable.

In the case of luminous tube sources, however, there is no time-lag and the discharge is extinguished each time the cycle passes through zero. Thus, when discharge lamps were first introduced for lighting, one of the main theoretical objections was that, due to the stroboscopic effect, they could not be safely used in situations where there was rotating machinery. In actual practice this effect was found to be slight as in most cases if one portion of a rotating machine appeared stationary the parts running at other speeds made it quite obvious that the machinery was in motion.

Nowadays, this flicker can easily be minimised to dispel any doubts about the utility of discharge tube factory lighting. This can be done (*a*) by operating adjacent lighting points on different phases of a three-phase supply; or (*b*) by arranging the lighting circuits so that discharge lamps are in conjunction with filament lamps; this, of course, also provides a certain amount of colour correction, but lowers the overall efficiency of the lighting.

High Pressure U.V. Lamps

The high pressure U.V. discharge lamp produces almost the entire mercury spectrum with good intensity. This type of lamp, together with its control circuit, is shown in Fig. 39. It is filled with inert gas and mercury in the same way as the low pressure lamp, but electrodes coated with alkaline earth oxides are used in order to provide a large number of electrons.

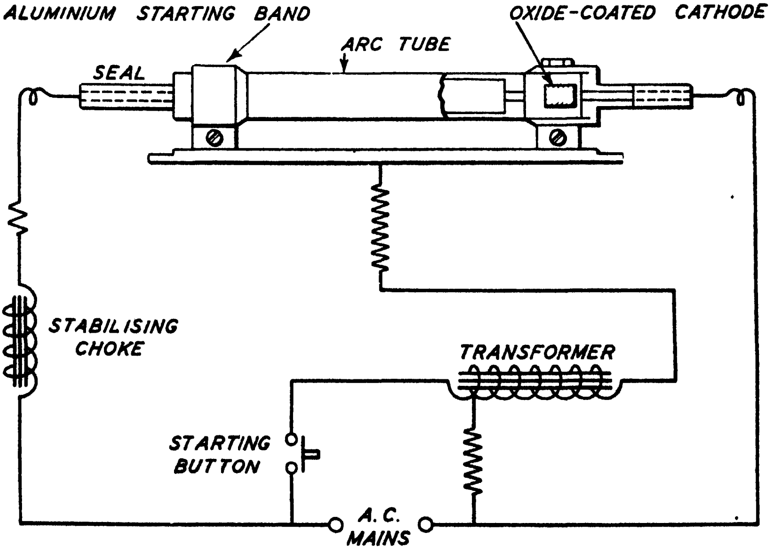


FIG. 39.—HIGH-PRESSURE U.V. LAMP WITH CONTROL CIRCUIT

Around the electrodes are aluminium starting bands to which, on pressing the starting button, a high voltage is applied from the transformer. Thus the discharge strikes up through the inert gas as in a cold cathode tube, but, under the intense ion bombardment, the electrodes quickly become hot and the oxide coatings emit more and more electrons. Since the mercury continues to vaporise, the internal pressure rapidly increases with a corresponding reduction in current until the stable condition is reached.

Usually, high pressure U.V. equipment for use on 230-volt mains starts at about 7 amperes and operates at 3·6 amperes; the value of the choke being 0·6 henries and the series resistance—to damp the comparatively heavy starting current—3 to 4 ohms. The apparatus may be used on D.C. supplies if the stabilising choke is replaced by a resistance.

If the quantity of mercury in the lamp is such that all of the mercury is evaporated by the time that normal operating temperature is reached, the lamp is known as a "saturated vapour lamp".

Life of Lamps

The life of the low pressure gaseous discharge lamp is determined by the rate of "sputter" or deposition of the electrode metal on to the surrounding glass. This, in turn, depends on the area, type and condition of the metal used, the internal gas pressure and several other details of manufacture. Nevertheless, a good lamp operated under correct conditions should have a minimum useful life of 2,500 to 3,000 burning hours.

High-pressure lamps, however, are not subject to the same amount of sputtering, since the cathode emission tends to neutralise the ionic bombardment. It has been found that in this case it is the life of the alkaline oxide coating that is the important factor. When the coating becomes "de-activated", the emission ceases and the lamp becomes inoperative. Here, again, it is a question of manufacturing technique, two of the principal items being the method of depositing the coating and the purity of the gas and mercury.

Radiation Emitted

Low-pressure lamps are an excellent source of intense monochromatic ultra-violet radiation, although owing to the small output in the visible region they appear to the eye to be a comparatively weak source. Actually, most of the radiation is of 2537Å. This is due to the fact that, since the current is small, most of the energy is a result of electronic impacts of the first excitation potential.

High-pressure lamps operate at a much greater current density, and the degree of ionisation is consequently much higher. The radiation from these sources is much more extensive and includes very little 2537Å radiation.

The low pressure discharge fills the tube, whereas the arc in the high pressure lamp is confined to a narrow path and has almost the appearance of a filament.

Black U.V. Lamps

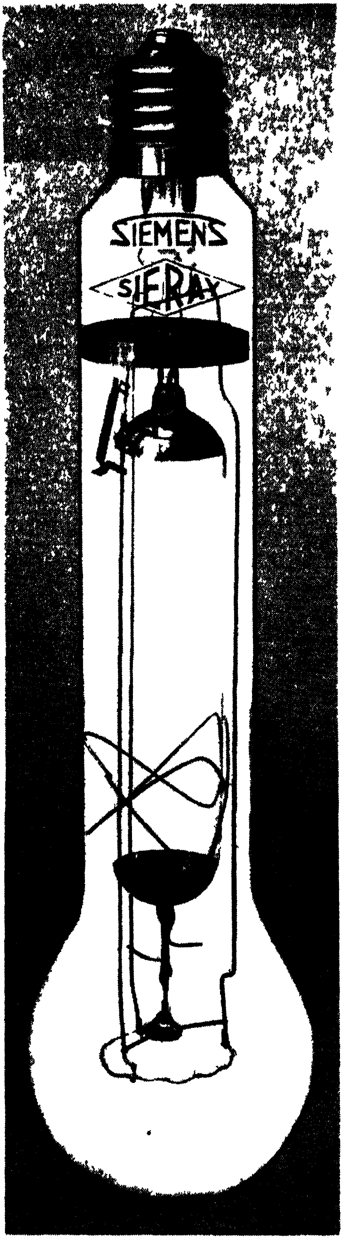
Since the glass bulbs of normal mercury discharge lamps do not transmit radiation of the requisite wavelength to activate fluorescent materials, a special glass has to be used. This is known as Wood's glass, and contains a quantity of nickel.

In effect, the black ultra-violet lamp is a high pressure mercury vapour lamp with a quartz inner tube and an outer bulb of Wood's glass which is opaque to visible light but allows free passage to ultra-violet rays of the necessary wavelength. Thus, the lamps are, with the exception of their outer bulbs, of exactly the same form of construction as the usual hot-cathode mercury discharge lamps, the choke coils and condensers required for their operation being of the same value.

The life of the black lamp, when properly installed, averages 1,500 hours burning. Direct exposure of the eyes and skin for prolonged periods at short range to the rays emitted from this lamp should be avoided. A feature of the lamp, which must be guarded against, is that when the outer bulb is accidentally broken it may continue to glow if the electrical connections to the element remain intact. In this eventuality it should be switched off immediately as, without the protection of the bulb, the radiation is very injurious.

Colour-corrected Lamps

The colour of the light normally emitted from mercury discharge tubes is, as is well-known, unsuitable for purposes in which colour discrimination is necessary. This is due mainly to a deficiency in red rays, which can be made up in two ways: (1) by combination with red ray emitting sources; (2) by fluorescence, although high pressure mercury discharge lamps produce only a small amount of ultra-violet rays having the correct wavelength to activate fluorescent powders.



(Siemens Electric Lamps & Supplies, Ltd)
FIG. 40 —SIERAY-DUAL LAMP

Sieray-Dual Lamp

The advantages of the Siemens Sieray-Dual Lamp over ordinary mercury discharge lamps are: (*a*) no choke or condenser is necessary for its operation; and (*b*) the light emitted is colour-corrected. The lamp can be screwed into any Goliath lampholder to operate direct off the supply mains.

As can be seen from the figure, the Sieray-Dual Lamp comprises a high pressure mercury vapour discharge tube connected in series with a tungsten filament. The filament takes the place of a choke coil by stabilising the arc of the discharge and, in addition, acts as a supplementary light source. The light emitted by the filament contains a considerable proportion of red rays which, in conjunction with the yellow-green radiation of the discharge lamp, produce resultant light of a pleasing colour.

Since the arc of the discharge is stabilised by the filament resistance, the power factor of the circuit is not unduly upset as with choke control, consequently the use of a condenser in the circuit is unnecessary. The power factor of the Sieray-Dual Lamp is approximately 0 95.

The main filament is connected to an auxiliary filament to prevent undue overloading on starting. Soon after first switching on, the auxiliary filament is automatically switched out of circuit by a thermal cut-out, naturally at a predetermined time in the run-up characteristic of the discharge tube. The lamp takes approximately 10 minutes to reach its full luminous output.

A further advantage of the Sieray-Dual Lamp is that it can be supplied for use on D.C. supplies.

Combinator Lamp

The Combinator Lamp, which unfortunately came on the market shortly before the outbreak of hostilities, consisted of a circular high pressure mercury discharge tube surrounding an ordinary gas-filled lamp of the required voltage and wattage to suit the tube characteristics. The two sources were combined in a compact unit by means of a special lampholder.

No choke or condenser was needed in the Combinator; the lamp started immediately on switching on and gave full efficiency after a few minutes; the light emitted was an approximation of natural daylight and could be used for colour matching. The price was amazingly low.

Since filament lamp and discharge tube were separate, the discharge tube had the normal long life of this type of source and when the filament burned out fresh gas-filled lamps could be easily plugged in.

Fluorescent Colour-corrected Lamps

In internal construction and operation these lamps are exactly similar to the high pressure mercury lamp, except that the inside of the outer glass bulb is coated with a fluorescent substance. Thus, a small proportion of the incident radiation is converted by fluorescence into rays of a different wavelength, resulting in the introduction of about 5 per cent of red rays in the light emission.

The average life of these lamps is 2,500 burning hours, but the efficiency is somewhat lower than that of an ordinary high pressure mercury lamp. A stabilising choke and power factor correction condenser are necessary for this type.

Chapter 7

THE NEW FLUORESCENT LAMP

This lamp is a form of electric discharge tube. Essentially it consists of a glass tube with an electrode sealed in each end, the flow of current taking place through mercury vapour with a small quantity of argon to facilitate starting.

Principle

The principle of the lamp is the same as that used in the Cooper-Hewitt lamp, which has been commercially available for nearly forty years. In the latter case the electrical characteristics, vapour pressure, current density and voltage are so regulated that the resultant discharge produces directly as much light as possible. In fluorescent lamps these elements are calculated so that the discharge produces very little visible light directly but crowds as much energy as possible into the ultra-violet radiation at one specific point—the 2537 line. Mercury is used as the conducting vapour because of its high efficiency in the production of ultra-violet radiation that activates the powders which are coated on the inside of the tube.

To attempt an explanation of the theory of fluorescence introduces more complications than those involved in the explanation of the production of light directly by the flow of electrons through a gas. The explanation of the property of materials which do fluoresce under the action of ultra-violet radiation is simply that such materials absorb energy at one wavelength, re-radiate it at longer wavelengths and thereby give out light over a continuous band of visible wavelengths.

Auxiliary Apparatus

Fluorescent lamps, in common with all electric discharge light sources, require auxiliary control equipment. This consists of: (1) an iron-cored choke coil to limit the arc current; and (2) a starting switch which momentarily closes and then opens the electrode heating circuit. Each lamp requires a separate auxiliary, though the elements or ballasts for two lamps may be in a single container. Specifically designed ballast equipments are necessary for each wattage size, for each frequency and for each voltage range.

Replaceable Starters

The obvious type of starting switch is the automatic type. However, the moving parts of this kind of switch render it liable to mechanical breakage and difficult to repair. A new type of switch has now been developed by the General Electric Company of Ohio, U.S.A., to whom acknowledgements are made for the material contained in this chapter. The switch is known as the "replaceable starter" and is shown in Fig. 41. A thermal glow switch and a radio interference condenser are fitted inside an aluminium container, the terminals being connected to each side of the lamp.

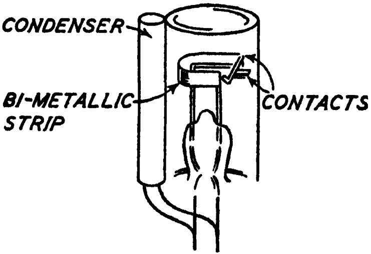


Fig. 41.—Replaceable Starter

On starting, the voltage at the starter is sufficient to produce a glow discharge between the bimetal and the centre electrode so that the heat produced causes the bimetallic strip to complete the lamp cathode heating circuit. Since the glow discharge is shorted out, the contacts soon open and the inductive kick from the ballast starts the lamp. The voltage at the starter is insufficient thereafter to cause the switch to operate, so that the starter consumes no energy during lamp operation.

Ballasts

A fluorescent tube ballast consists of an iron-cored choke coil which is connected in series to limit the current. Because of its induction, the ballast gives a low power factor and this has to be corrected.

Fig. 42 shows two schematic diagrams of two-lamp circuits. One of these is a series circuit enabling the two lamps to be controlled by a single ballast or choke winding. This is practicable where a mains voltage of 400 is available. The second diagram shows a parallel circuit with separate ballasts for each lamp with a condenser in one lamp circuit to produce a phase displacement and thus minimise the stroboscopic effect.

Due to the magnetic action in the choke coils, there is a slight hum from the ballasts, but this may be minimised by mounting auxiliaries on soft rubber mountings.

Supply Voltage

For fluorescent lamps the lamp voltage decreases with increase of line voltage and, although the lumen output increases as the line voltage goes up, the efficiency actually decreases. This is due to the fact that increased line voltage causes the choke to pass more current to the tube, thus lowering the resistance of the discharge path and resulting in a lower voltage drop across the lamp itself. And, although the input to the lamp is increased, the lumens are only increased over a certain range which does not include the ultra-violet radiation.

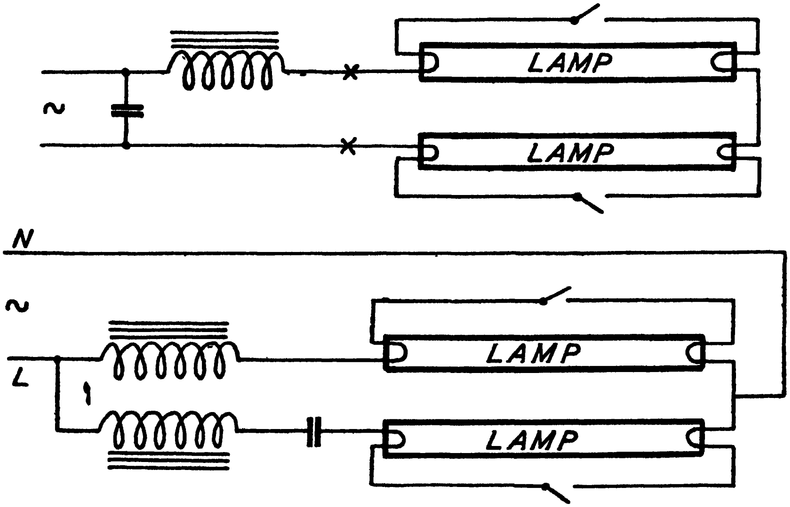


Fig. 42.—Schematic Diagrams
(*Top*) Two-Lamp Series Circuit.
(*Bottom*) Balanced Inductive-Capacitative Circuit for two Lamps.

In Fig. 43 characteristic curves are given for different values of line voltage. Since line voltage is an important factor in starting, it should be remembered that voltages below that for which the equipment is rated will result in unsatisfactory starting. Similarly, inferior performance and overheating will be caused by excessive over-voltage.

Frequency and Flicker

On account of the cyclic variation in alternating current, the light output from discharge lamps is not strictly uniform; the lower the frequency, the more obvious this becomes. Contrary to filament lamps, no energy is stored in discharge tubes and the light output drops almost to zero between each half-cycle. In fluorescent lamps this effect is reduced by the persistence of glow of the fluorescent powder.

A method of reducing the light fluctuation still further consists in operating the lamps on two or more phases with a two-lamp ballast so that the lamps will operate out of phase.

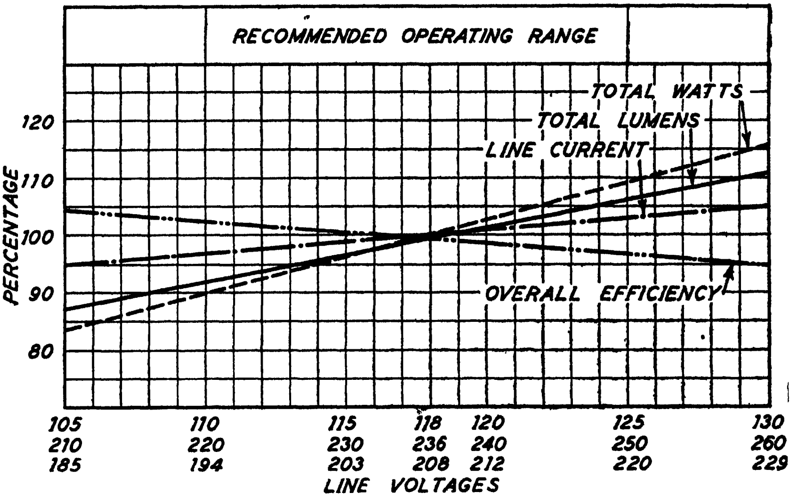


FIG. 43.– CHARACTERISTIC CURVES OF TYPICAL TWO-LAMP BALLASTS

Operating on Direct Current

Whilst fluorescent lamps are primarily designed for A.C. operation, they may be used on D.C. circuits by using a specially designed auxiliary and including in the circuit a series resistance. Glow switch starters are naturally not suitable in this case. Unfortunately, using fluorescent lamps on direct current supplies usually results in decreased efficiency.

However, colour quality and total light output of D.C. operated lamps compares favourably with that of those used on A.C. and the stroboscopic effect is entirely eliminated.

Effect of Length on Efficiency

The voltage of a fluorescent tube may be divided into the electrode drop and the potential gradient of the positive column (luminous part of the arc stream). The electrode drop is usually somewhere between 12 and 18 volts, depending on electrode size, cathode emission and filling gas.

Potential gradient is the voltage required per inch of tube to make up for energy losses and the conversion of energy into radiation. Since the electrode drop remains practically constant, efficiency increases as lamp length is increased but, as shown in Fig. 44, at a decreasing rate.

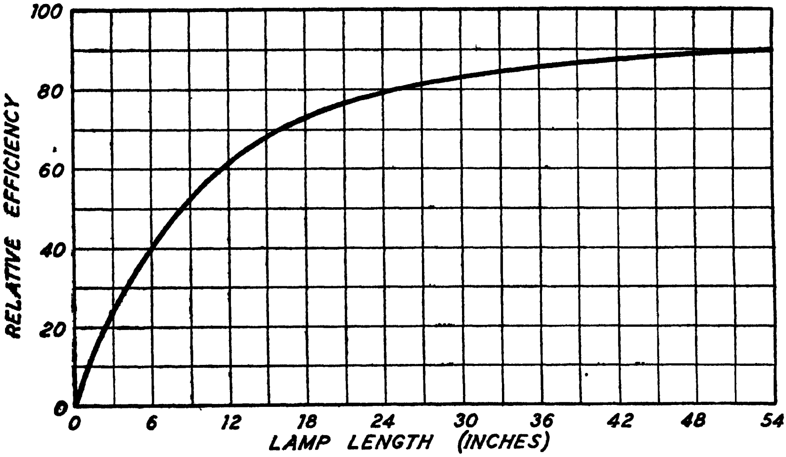


Fig. 44.—Effect of Lamp Length on Efficiency

Effect of Tube Wall Temperature

At too low temperature the mercury condenses and the ultraviolet radiation is reduced; at too high temperature the vapour pressure is increased and some of the radiation is changed from 2537Å to longer wavelengths. There is also increased re-absorption of the 2537 radiation by the vapour. In Fig. 45 temperature of lamp is compared with relative light output. The adverse effect of low air temperature can be offset to a great extent by protective enclosures.

Conversion to 2537 Radiation

The efficiency of conversion of energy input in a lamp of given diameter to 2537 radiation increases somewhat as the current density is decreased. Although increasing the diameter of the tube whilst keeping the same current value would tend to increase the efficiency, the gain would be diminished because of the failure to maintain the optimum bulb wall temperature. The curve shown in Fig. 46 is for a 1-inch diameter tube at 104° F.

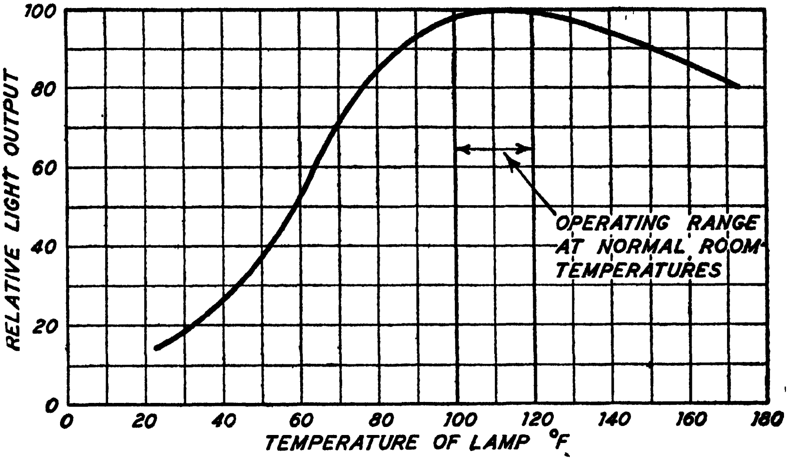


Fig. 45.—Effect of Tube Wall Temperature

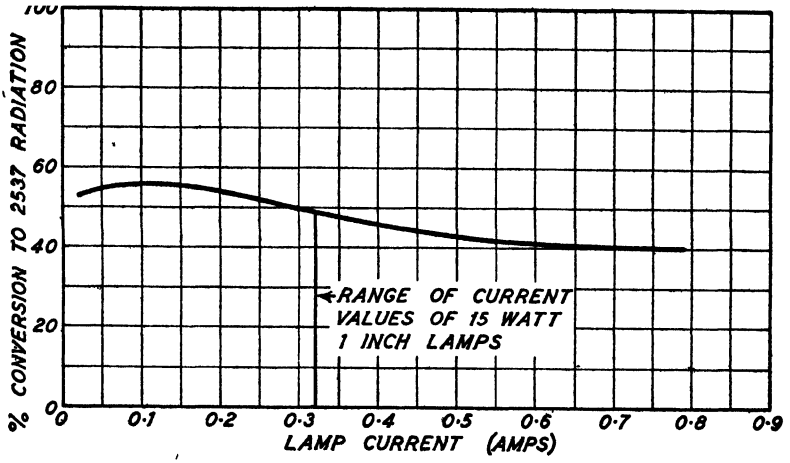


Fig. 46.—Conversion to 2537 Radiation

Sensitivity of Fluorescent Powder

For the most efficient operation of fluorescent lamps, the powder used should have its maximum response at the particular wavelength of ultra-violet generated (Fig. 47). Since no other ultra-violet line of the low pressure discharge in the fluorescent lamps is as much as 4 per cent of the 2537 line, whenever possible powders are selected with their maximum sensitivity between 2500 and 2600Å.

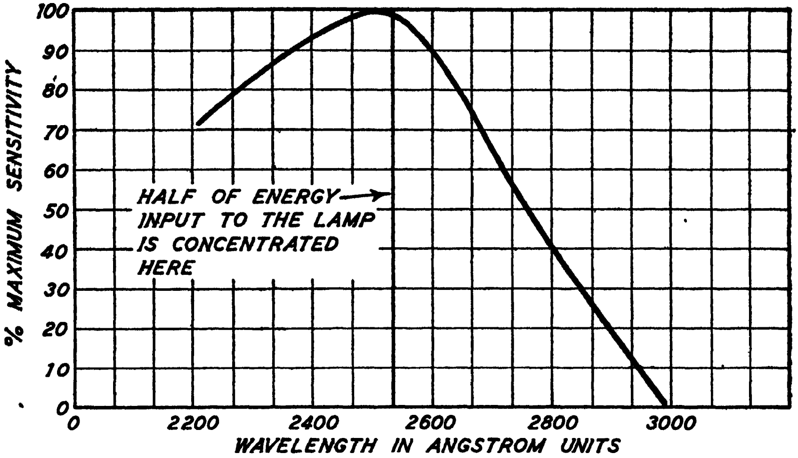


FIG. 47.—SENSITIVITY OF FLUORESCENCE

Colour Temperature

Fig. 48 is a colour temperature chart comparing Mazda fluorescent and incandescent lamps with natural daylight which shows definitely that daylight can be matched by fluorescent discharge tubes. Colour qualities of a light source can only be measured accurately by determination of spectral distribution. But since the number of foot-candles must also be taken into account, it is essential that comparable illumination is given by the sources under comparison. The Mazda[1] white fluorescent lamp is designed to give a 3,500°K colour temperature, the daylight lamp 6,500°K. Various combinations of fluorescent lamps can be arranged to produce almost any colour temperature.

In Fig. 49 the spectrum is divided into bands of minimum perceptible colour differences. In most bands the differences are small. The red deficiency of the fluorescent tube is in the deep red where the luminosity is low.

Radiant Heating Effects

Confusion is sometimes expressed at the assertion that fluorescent lamps produce cooler foot-candles than do incandescent lamps.

Whilst a kilowatt-hour represents a heating effect of 3,414 B.T.U.'s regardless of how consumed, the lesser sensation of heat from fluorescent lamps lies in the fact that only about 35 to 45 per cent of the energy is radiated as heat as compared with 75 to 85

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[1] General Electric Company of U.S.A.

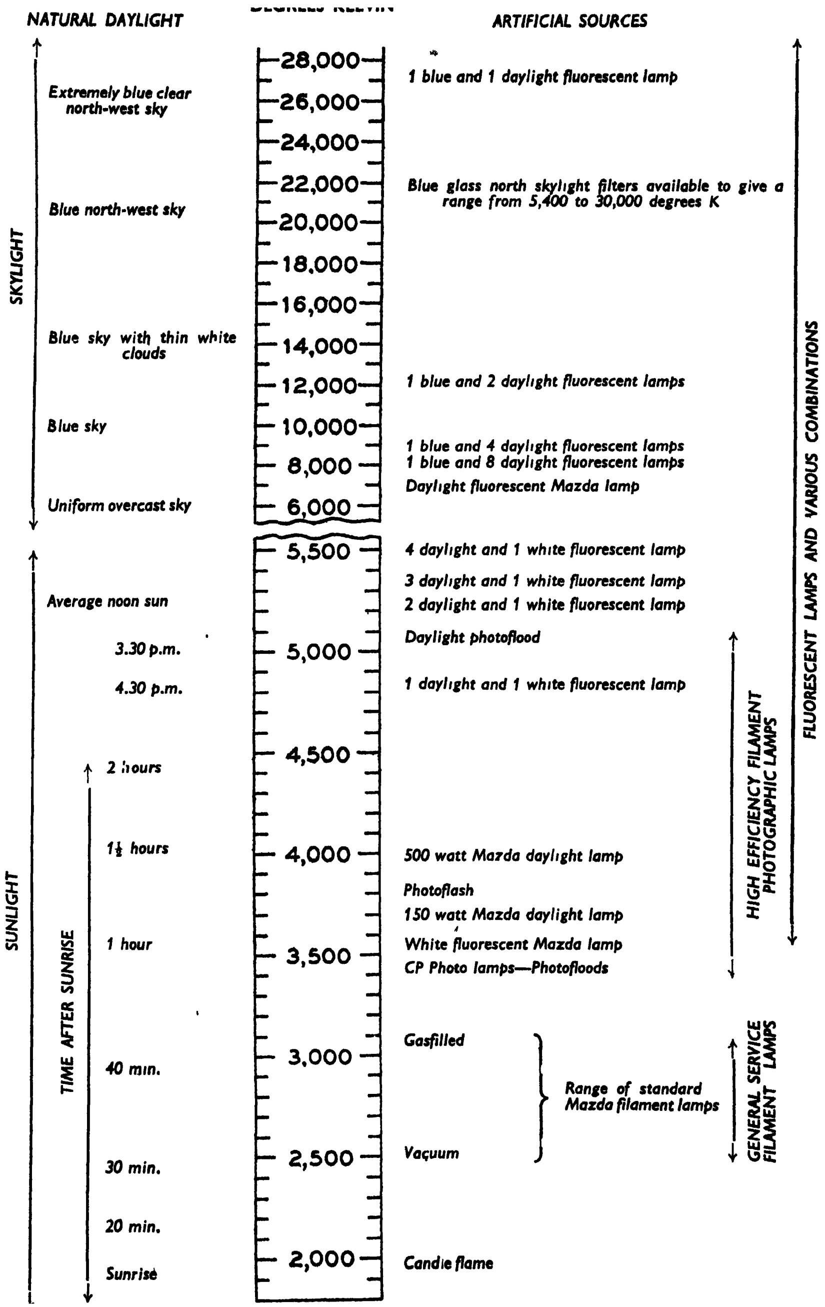


FIG. 48—COLOUR TEMPERATURE CHART

per cent for filament lamps. Thus the radiant heat from fluorescent lamps is only about half that of filament lamps whilst the efficiency of the former is double the efficiency of filament lamps.

Thus the sensation of heat from the fluorescent lamp is roughly one-quarter that given by filament lamps of equal light output.

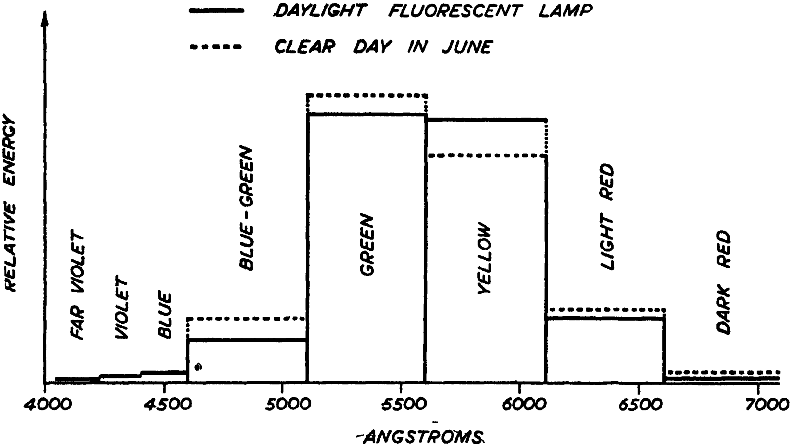


FIG. 49.—
COMPARISON BETWEEN DAYLIGHT FLUORESCENT LAMP AND NATURAL DAYLIGHT

Efficiency and Lamp Operating Temperature

Fluorescent lamps operate at highest efficiency at room temperatures of about 70 to 80° F., where the temperature of the glass tube is itself from 100 to 120° F. At normal temperatures the lamps maintain their efficiency even when installed in exposed positions out-of-doors. However, during the winter months the light output falls off somewhat although no operating difficulties should be experienced.

Useful Life

The useful life of fluorescent lamps is generally determined by the blackening of the tube due to the effect of the mercury on the fluorescent coating, and, in addition by sputtering of the electrodes. It has been found that the rate of depreciation diminishes throughout life; the first 100 hours operation produces the same blackening as the subsequent 1,000 hours.

Frequent starting of lamps may take more life out of the electrodes than long hours of burning, because momentarily this results in an abnormal voltage drop at the electrodes, thus causing excessive sputter. If a fluorescent lamp is started once a minute, for example, the hours of efficient operation will be shorter than normal, but if it were switched on and operated continuously its life would be longer than normal.

When the active material on the electrodes is nearly exhausted, the voltage required for starting will rise and will equal and eventually exceed the supply voltage. This may occur after the lamp has been started thousands of times or burned beyond its rated life.

Chapter 8

DATA AND TESTS

MENTION has already been made in Chapter 1 of the possibilities of the low pressure cold-cathode as a source of illumination. The following pages consist of a collection of data which was mostly obtained as a result of practical tests in this connection.

The developments in fluorescence have done much to enhance the cold-cathode tube light source, both in colour blending and in actual light output.

Fluorescence

Fluorescing, as applied to luminous tubes, consists of treating the tubing with a layer of luminescent powder such as zinc orthosilicate, calcium tungstate or heat-treated metallic oxide. The luminescent material may be applied in a thin film to the inside wall of the glass tubing or may even be introduced into the composition of the glass.

When applied directly to the tubing a binder consisting of glycerine, potassium silicate, acetone-diluted phosphoric acid or other suitable adherent liquid is used. Separate binders are generally required for neon-filled and argon-with-mercury vapour tubes. The reason for this is that the action of the binder in mercury tubes, although primarily intended to attach the luminescent powder to the tubes, also prevents the reaction between vapour and powder which tends to blacken or shorten the effective life of the tubes. A binder suitable for argon-with-mercury vapour tubes must therefore be such that a protective film is deposited on the powder. Fluorescent tubes are usually processed at temperatures of from 375 to 400° C. for a minimum period of one hour.

The precise action of fluorescent tubes is rather obscure. Argon-with-mercury vapour tubes emit radiation with a wavelength of between 2,000 and 4,000Å, and the obvious conclusion is that the luminescent powder is excited by the ultra-violet radiation of the discharge. If this were solely the case, no excitation would be produced in tubes containing neon or neon with a trace of helium for, in this case, the radiation is of a wavelength below 2,000Å. Actually, quite satisfactory results are obtained from the latter, even when using the same luminescent powder as for the argon and mercury vapour discharge.

Comparatively high efficiencies are obtained from fluorescent tubing, as is shown by Table 14, but in the case of mercury vapour tubes depreciation is greater than when rare gases alone are used. The tests were made on tubes 5 feet long, 15 millimetres in diameter, fitted with Swedish Iron electrodes and operated by a transformer with secondary voltage 5,000 and at a current density of about 35 milliamperes per square centimetre.

Tests made with very low pressure tubes and using treated electrodes yielded rather promising results. The tubes were neon-filled and the electrodes were coated with an alkaline earth peroxide which was subsequently dissociated by the heating produced during bombardment.

TABLE 14

Characteristics of Fluorescent Luminous Tubes

COLOUR	FILLING	INITIAL LUMENS PER WATT	DEPRECIATION FACTOR (expressed as % loss after 1,000 hours)
Green	Argon & Mercury Vapour	30	22
Blue	Argon & Mercury Vapour	15	18
Gold	Argon & Mercury Vapour	25	20
Yellow	Argon & Mercury Vapour	15	18·5
White	Argon & Mercury Vapour	15	10·6
Amber	Neon & 1% Helium ..	20	9·5
Pink	Neon & 1% Helium ..	25	10
Orange	Neon & 1% Helium ..	10	7·5

INSTALLATIONS

Tubes of one colour only are not suitable for general purpose interior lighting, since there is bound to be a deficiency in rays of at least one colour. For most situations a combination of three tubes is found necessary to make colour discrimination possible.

An important advantage of luminous tubes for decorative lighting is their low surface brightness (see Table 15) which permits their installation in full view of the public without glare. In addition, they can be used to create an appropriate atmosphere. When installed in a restaurant for example, the colours would be separately switched so that on a hot day a bluish light would give the impression of coolness, whilst in the winter a warm orange glow would serve to counteract the depressing influence of cold or damp weather.

For store or factory lighting the best results would probably be obtained by arranging the tubing in three-colour formation throughout the length (or breadth) of the ceiling. In lofty premises it may be necessary to suspend the tube sections from the ceiling by means of hanging-brackets spaced at intervals, so as to bring the tubing to a height of, say, 10 feet from the floor.

The general arrangement of one circuit of such an installation is shown in Fig. 50, by which it will be seen that the centre points of both transformer secondary and the luminous tubing are earthed, thereby ensuring minimum voltage stress.

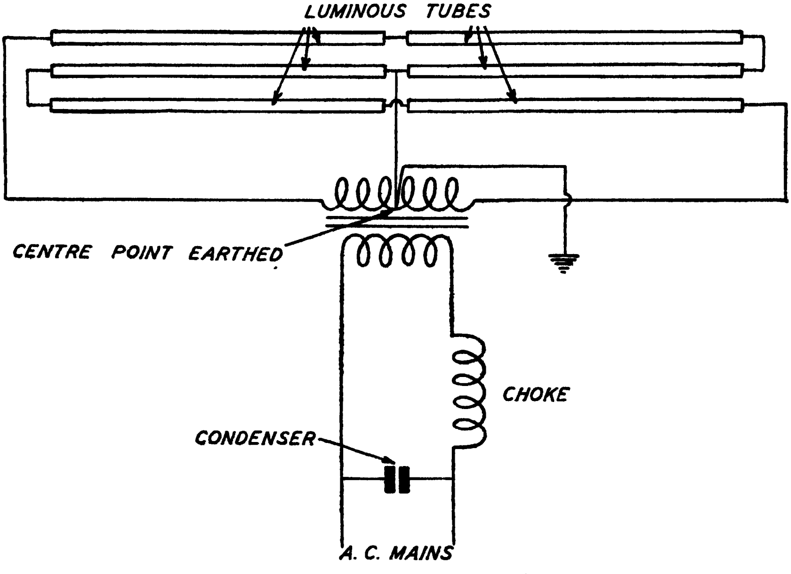


FIG. 50.—GENERAL ARRANGEMENT OF HIGH-VOLTAGE TUBE CIRCUIT

All electrodes and high-voltage connections are housed in metal cases which should be efficiently earthed. Assuming a length of 10 feet, a lighting intensity of from 10 to 12 foot-candles could be obtained, the consumption of each section of tubing being approximately 100 watts.

In comparing this with other sources of illumination it should be remembered that a perfectly uniform distribution of light can be provided and shadow practically eliminated, which is generally advantageous for industrial purposes.

TABLE 15

Comparison of Surface Brightness of Various Light Sources

CANDLE FLAME	1·0
BLUE L.P. LUMINOUS TUBE	1·5
60-WATT PEARL G.F. LAMP	3·5
100-WATT PEARL G.F. LAMP	11·0
250-WATT H.P. MERCURY LAMP	65·0
400-WATT H.P. MERCURY LAMP	90·0

A similar type of lighting can be used with great success for shop windows, the triple-tube sections being fitted with suitable reflectors which would serve also to render the tubes invisible from the pavement. Discharge-tube window lighting is particularly useful for obtaining various colour effects. For instance,

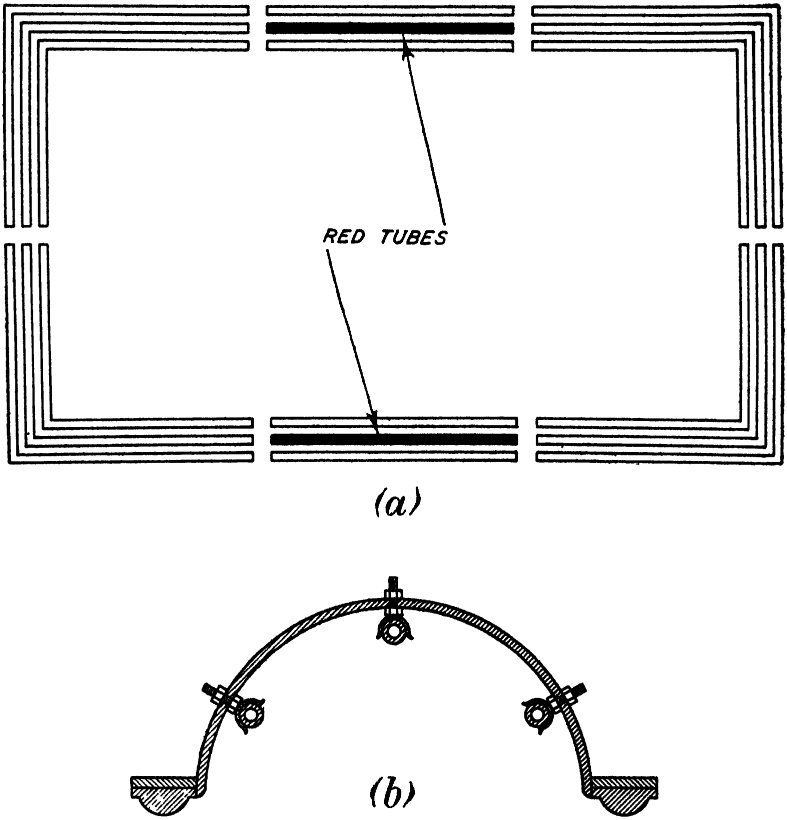


FIG. 51.—LUMINOUS TUBE LIGHTING FOR A SMALL OFFICE SHOWING:
(a) General arrangement (b) Section through channel

some merchandise is displayed most effectively by light which gives prominence to either the blue or red end of the spectrum. It is then quite a simple matter to arrange the colour combination of the tubes accordingly.

Although still in the experimental stage, luminous tube office lighting is being developed considerably. Fig. 51 shows an installation designed for a small office with a floor area of about 300 square feet and a ceiling height of 10 to 15 feet.

A deep channel reflector is built into the ceiling equi-distant from the walls and the luminous tubes are suspended therein. The channel reflector, which is treated with a special white paint of high reflection factor, has a total radiating area of 25 square feet.

The luminous tubing is luminescent with the exception of two single lengths of red which provide a certain amount long wavelength light output of the red portion of the spectrum. The resultant blending gives a soft light similar to natural daylight. In operation, the tubes are supplied by transformers with an output of 60 milliamperes at 5,000 volts.

When measured with a foot-candle meter provided with a correction filter to approximate to the human eye response, a reading of 15 foot-candles was obtained. This reading was taken underneath the tubes at desk height, the minimum illumination in the middle of the room being 12 foot-candles.

For public buildings it is recommended that the luminous tube lighting be supplied in units, each triple-tube section fitted on galvanised steel troughing and operated by its individual transformer. The interior of the troughing is utilised for housing so that the electrodes, series connections and high-voltage leads are totally enclosed and protected and continuity is provided for by earthing lips welded on to the end of each length of troughing.

The luminous tubes can be secured by means of phosphor-bronze clips, which also serve as connections, secured to the top of the troughing. The end covers of the troughing are arranged to slide, which not only facilitates installation of the lighting but permits disconnection and removal of the tubes for maintenance.

Lead covered high voltage cable of the ozone proof type should be used for secondary circuit wiring and it is advisable to protect all high-voltage feeder connections with special compounded bell-insulators.

Fig. 52 shows a pictorial luminous tube frieze design suitable for hotels, restaurants, theatres or other catering establishments. The maritime scene is first painted with special colour on a background of some fireproof material, which is mounted at some distance from the wall so that all unsightly H.T. connections can be concealed at the back. Such a scheme is, naturally, only used as auxiliary to the general lighting (preferably luminous tubing) and the colours must be carefully chosen so that the resultant light given by the whole will harmonise with surroundings.

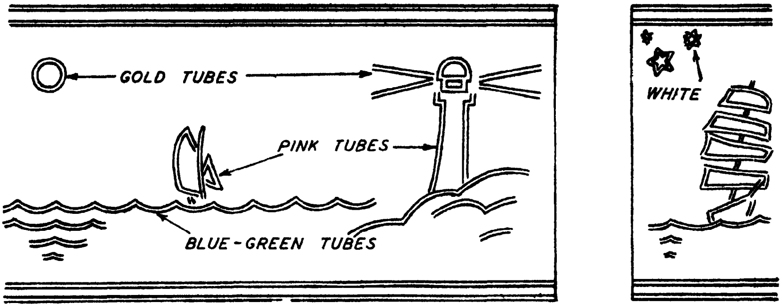


Fig. 52.—Pictorial Luminous Tube Decorative Frieze Lighting

The reflection factors of various colours are given in Table 16 from which it will be seen that the best colours to use for the maritime frieze are—golden-yellow (moon, reflections and lighthouse rays)—eau-de-nil (line of sea)—salmon pink (ships and lighthouse) and white for stars.

TABLE 16

Reflection Factors of Various Colours

White	84	Salmon pink ..	44
Golden yellow ..	80	Sea green	38
Primrose	76	Sky blue	30
Pale cream ..	76	Light brown ..	27
Lemon yellow ..	69	Signal red ..	17
Light buff ..	61	Turquoise blue ..	15
Eau-de-nil ..	47	Peacock blue ..	11

Colour

It is now an established fact that light of the yellow-green portion of the spectrum is the most efficient. The luminosity curve as adopted by international agreement is shown in Fig. 53. From this it is apparent that radiant energy with a wavelength of $\cdot 55\mu$ produces the greatest sensation of light. Sources emitting light of the orange-yellow or blue-green portions will therefore only radiate approximately half of the energy that would be radiated by a yellow-green source in a given time.

Obviously, if an efficient light source irrespective of colour is required sodium vapour lamps are the best proposition as these sources give almost monochromatic yellow light with an initial efficiency of from 50 to 70 lumens per watt. If sodium lamps are used, however, all coloured objects will appear as neutral tints or black. A similar disadvantage would apply if the slightly less efficient mercury vapour lamp were to be used. From Fig. 54 it is seen that the next light source in order of efficiency is the low pressure high-voltage discharge tube.

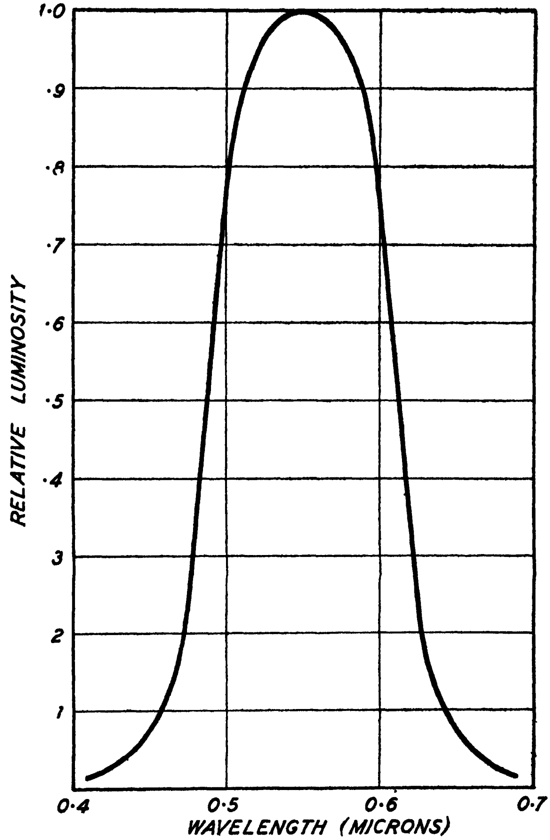


Fig. 53.—Standard Luminosity Curve

Experiments with various colour combinations of fluorescent tubing show that high efficiency for general purpose lighting is given by either one gold tube or one pink tube with two green tubes. Table 17 gives a comparison of various three-colour schemes.

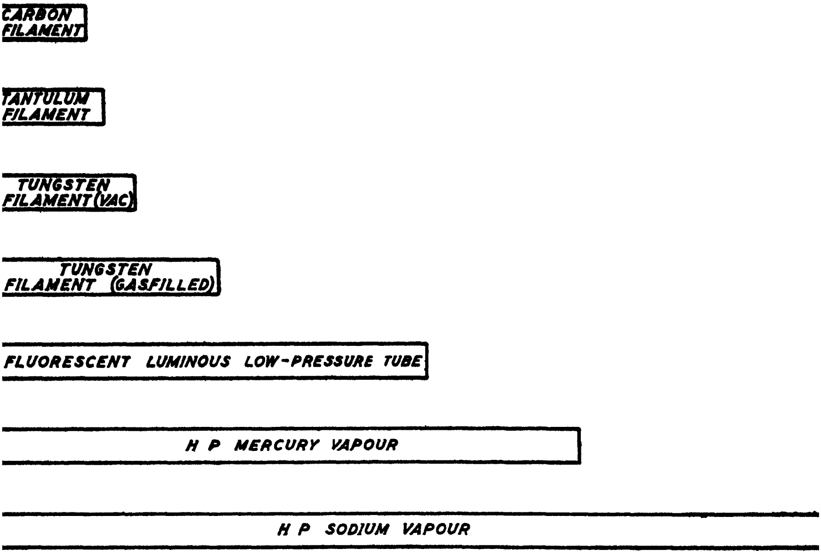


Fig. 54.—Comparative Efficiencies of Various Light Sources

TABLE 17

(*a*) *Utilities of Triple-Tube Colour Combinations*

COMBINATION	RESULTANT COLOUR	REMARKS
1 red tube and 2 green	Soft pink-white	Very cheerful, suitable for cinema and theatre foyers, etc.
1 green tube and 2 gold	Warm amber	Suitable for display purposes unless blue is predominant colour.
1 red tube and 2 white	Pink-white	Colder than other combinations but suitable for general lighting.
1 red, 1 green and 1 blue-green	Almost white	Applicable to indirect lighting schemes and separate colour control.
1 red, 1 green and 1 gold	Pink-amber	Suitable for restaurants, etc.

TABLE 17

(*b*) *Characteristics of Various Three-Colour Combinations*

COMBINATION	RESULTANT COLOUR	TONE	APPROX. INIT. LUMENS PER WATT (overall)	WATTS PER FOOT (overall)
2 green and 1 gold	Greenish-yellow	Rather warm	25	21·5
2 green and 1 pink	Yellow	Warm	25	20
2 gold and 1 green	Greenish-white	Deficient in red	23	21·5
1 green, 1 gold and 1 pink	Yellowish-white	Cheerful	23	21·5
2 white and 1 pink	Almost white	Rather cold	15	20
2 amber and 1 green	Yellow	Deficient in blue	20	18·6

Air Condition

Of every 100 watts consumed by an incandescent electric lamp at least 90 to 95 watts appear as heat, this being approximately equivalent to the heat given off by an adult human being. Thus a room 40 feet by 60 feet long, illuminated by twenty 500-watt incandescent lamps would undergo a temperature rise equal to that caused by 100 people.

Considering the question solely from the point of view of comfort, there is an additional disadvantage of filament lamps; that of skin temperature as distinct from room temperature. The incandescent lamp is a fairly efficient generator of infra-red rays which produce on the skin a sensation of heat that is not indicated by a thermometer. Infra-red radiation can make a person uncomfortable in a room in which ice would not melt. It is difficult to remedy this condition by refrigeration.

In an efficient high-voltage fluorescent discharge tube 15 watts out of every 100 appears as light, as compared with 5 to 10 for an incandescent lamp and, in addition, only a fraction of the infra-red radiation of the latter is produced.

Variation of Voltage Drop with Pressure

Both the light and the electrical resistance of luminous tubes are affected by the gas pressure. If there are a large number of gas atoms in the path of the electron stream the speed of the latter will be reduced to a point where no further electrons can be separated from the atoms and ionisation will be lowered. If, on the other hand, there is a scarcity of atoms proper ionisation cannot take place, since there is then less opportunity for collision between electrons and atoms. Thus, too great a pressure results in longer life but higher resistance, whilst insufficient pressure will tend to reduce the life.

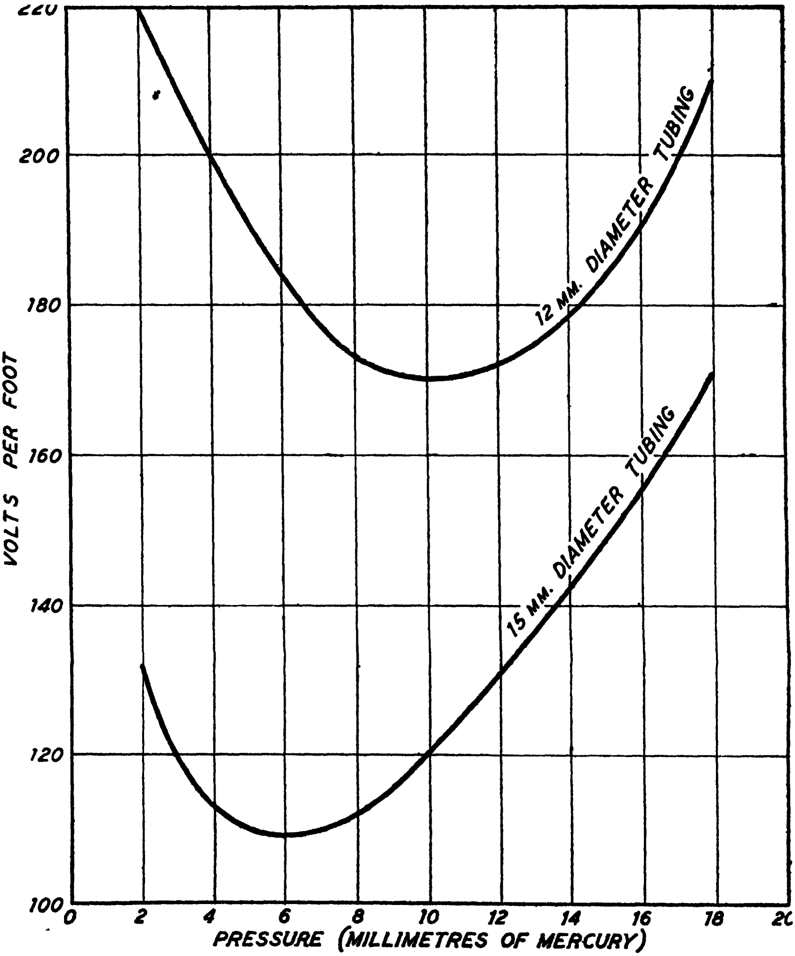


FIG. 55.—VARIATION OF VOLTAGE DROP PER FOOT WITH PRESSURE

The curve (Fig. 55) shows the variation of voltage drop per foot with pressure and indicates that a decrease in pressure has much more effect on the electrical resistance than a corresponding increase. Due to the gradual hardening of the tubes by "sputter" effect, the optimum point as shown by the curve is not generally the best to use, particularly in the case of uncoated electrodes. Recommended pressures for three different sizes of tubing using coated and uncoated electrodes are given in Table 18.

Operating Voltage

The secondary voltage required to operate a given amount of tubing is a function of its diameter and length. One practical method of arriving at the correct voltage is given by what is known as a reduced voltage test. A standard tapped transformer is used by means of which the voltage output is regulated by turning a knob, a voltmeter, reading from 0 to 250 volts, being included in the primary.

The length of luminous tubing under test is connected to the transformer secondary and the knob rotated until a point is reached at which the tubing flickers. From the primary input at this "flicker point" the correct loading can be obtained, the precise calculation depending on the size and type of test transformer. In a purely hypothetical case, if the tubing flickered whilst the voltmeter reading was between 150 and 170 the correct loading was obtained. If the flicker point was above 170 volts or below 150 volts then the tubing was under-volted or over-volted respectively.

It is well known that, using the same transformer in each case, the light efficiency of luminous tubes increases with length up to a maximum value which is determined by the approach of the striking potential of the tubes to the open-circuit voltage of the transformer. In practice, the striking potential of the tubes should be at least 20 per cent below the open-circuit voltage of the transformers operating them.

TABLE 18

Recommended Gas Pressures

DIAMETER OF TUBING	OPTIMUM VALUE	RECOMMENDED GAS PRESSURE ALLOWING FOR ABSORPTION	
		Uncoated Electrodes.	Coated Electrodes.
10 mm.	12 mm.	15 mm.	14 mm.
12 mm.	9 mm.	11 mm.	11 mm.
15 mm.	6 mm.	10 mm.	8 mm.

Operating Current

In Fig. 56 operating current is plotted against efficiency in lumens per watt of different colours and diameters of luminous tubing.

Measuring Luminous Intensity and Flux

For test purposes it is best to use a standard length of luminous tubing and cover each end with opaque paper so as to leave one clear foot in the centre. The foot-candle meter, which is fitted with a filter to approximate the spectral sensitiveness of the human eye, is arranged underneath the centre of the tube at a distance of one foot and the meter deflection caused by the luminous tubes is compared with those caused by a standard illuminant (e.g. a gauged incandescent lamp).

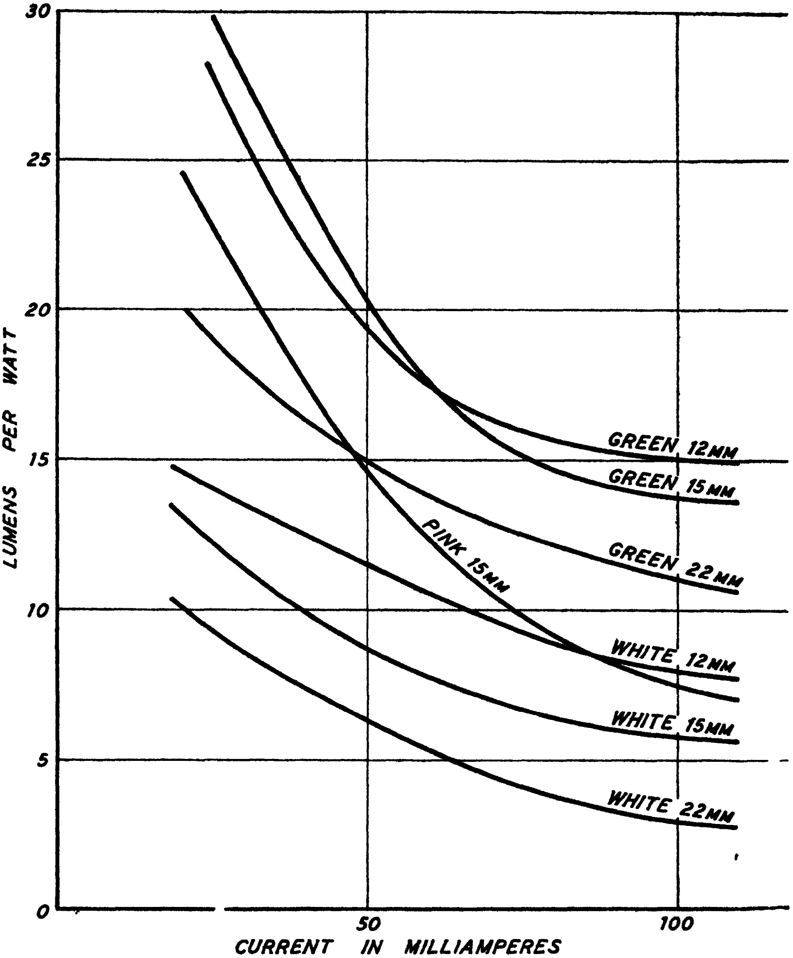


FIG. 56.—VARIATION OF EFFICIENCY WITH OPERATING CURRENT AND TUBE DIAMETER

The light intensity of the luminous tubes (foot-candles) is then obtained by dividing the deflection caused by them by the deflection caused by the standard and multiplying the result so obtained by the light intensity of the latter at one foot.

The calculation of lumens per foot is based on the assumption that planes of the same light intensity resemble the planes of a cylinder with the luminous tube as a common axis. Therefore, the longer the luminous tube under test, the more correct will be the calculation of luminous flux and the opaque paper should not be used.

Efficiency of luminous tubes in lumens per watt is usually stated in conjunction with length in order to give fair comparison, since the wattage of a luminous tube is not exactly proportional to its length.

As it is not always possible to process luminous tubes with precise uniformity, quite a number of small deviations are likely to occur in calculations with apparently similar tubes.

Spacing of Single Fluorescent Tubes

Where general lighting by means of individual rows of tubing is required, the necessary spacing can be calculated from the formula:

$$D1 = \frac{K \times Lmax}{FI \times Fb}$$

in which $Lmax$ is the maximum lighting intensity required and K, FI and Fb are values taken from Table 19. The diameter, operating current and colour of the luminous tubing are constituents of Fb, the comparative length of the tubing is expressed by FI and the factor corresponding to the vertical distance of the tubes from the plane to the lighted A is represented by K.

For example, a room 28 feet long by 10 feet high is to be illuminated by parallel lengths of luminous tubing so that a general lighting of an intensity of 10 foot-candles is to be produced at a distance of 7 feet from the ceiling using white tubing of 22 mm. diameter operated at 60 mA.

Then by reference to the table $Fb = 283$, $FI = 1{\cdot}72$ and $K = 87$.

Thus, $DI = \frac{87 \times 10}{1{\cdot}72 \times 283}$ = approx. 1·79 foot.

Life of Tubes

The rare gas in a luminous tube is not, of course, consumed but simply undergoes a temporary change with the passage of the current. Since the ions return to their normal state when the current flow is stopped, it would appear that the life of a luminous tube should be unlimited. This, we know, is not the case. The chief factor affecting the life is the process known as "hardening" during which the pressure gradually decreases and the voltage drop across the electrodes rises until eventually the tube begins to flicker. However, with carefully processed tubing, flickering would not commence before at least 5,000 burning hours had elapsed. When hardening does take place, the luminous tubes can be re-gassed at a fraction of their original cost.

TABLE 19

Values for Calculation of Single-Tube Spacing

		VALUES FOR fb			VALUES FOR fl		VALUES FOR fl		VALUES FOR K	
Milli-amps.	Diam. of Tube. mm.	White.	Pink.	Green.	Length of Tube divided by Height.		Length of Tube Divided by Height.		Distances A.	K.
15	15	108	78	79	0·3	0·35	2·5	1·63	3	116
30	15	210	159	154	0·4	0·46	3·0	1·68	5	101
60	15	368	282	284	0·5	0·56	3·5	1·71	7	87
15	22	68	53	63	1·0	1·00	4·0	1·72	9	73
30	22	149	107	122	1·5	1·33	4·5	1·74	11	59
60	22	283	210	233	2·0	1·52	5·0	1·76	—	—

A hardened tube which has ceased to be capable of maintaining a luminous discharge is found to have a thin film of metal deposited on the interior of the glass envelope immediately surrounding each electrode. The widely accepted theory as to the cause of this is that free particles of the electrodes, having attained negative charges, combine with the gas ions and trap them by electrostatic action on to the glass. This process, which is generally known as "sputtering", depends on the dimensions and material of the electrodes, the pressure of the gas, the current density and the treatment during processing. The effects on sputtering of slight gas impurities and absorption by the glass envelope are so small that they may be neglected. Thus the effective life of a cold-cathode luminous tube is proportional to

$$C\frac{p^{x}V}{i\,w}$$

in which p is the pressure (the normal value of the exponent x being 2) i is the current density, V the volume of the tube and w

a function relating to the periodicity of the supply. C is a variable quantity dependent upon the gas filling, electrode material and other details of manufacture.

Fluorescent-Glass Tubes

Fig. 57 shows the light efficiency and intensity of a white fluorescent-glass tube (in which the luminescent material is introduced into the composition of the glass) operated at currents up to 250 milliamperes. The tube was illuminated for an hour before the tests were taken in order to obtain equilibrium of temperature and vapour pressure, and measurements were taken at both rising and falling currents.

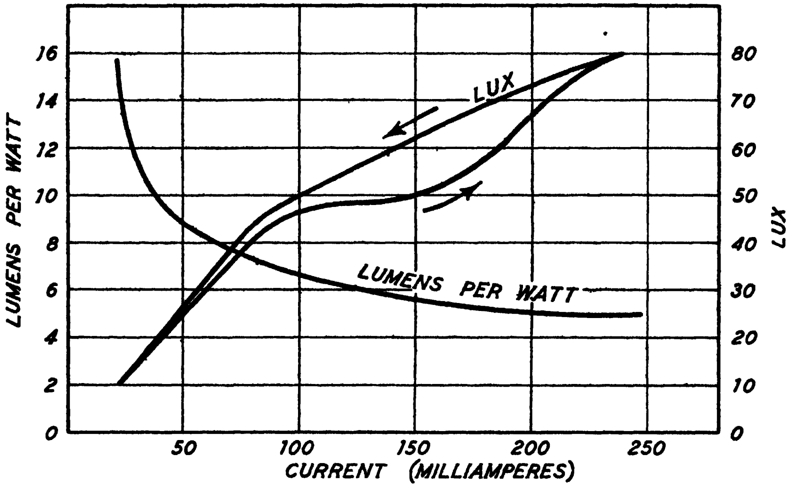


FIG. 57.—LIGHT EFFICIENCY AND INTENSITY OF FLUORESCENT WHITE LUMINOUS TUBE AT STRONG CURRENT

The curve for falling milliamperes indicates that the light intensity increased rapidly with increase of current and up to about 80 milliamperes the luminescence of the glass contributed much to the light output. At currents above this the tube became more akin to a high-pressure discharge lamp emitting U.V. radiation of too long a wavelength to excite further luminescence; with rising milliamperes, the values of light intensity were somewhat lower, which might possibly have been due to the comparative coolness of the glass.

In the case of the efficiency curve, average values were taken for rising and falling currents.

Fig. 58 shows the results of an attempt to compare the excitability to luminescence of two fluorescent-glass tubes. In order to eliminate as far as possible the effect of temperature, a quartz luminous tube was inserted into each length of fluorescent-glass and measurements of visible radiation of the quartz tube were subtracted from the resultant light obtained from the combination. This, however, is not a true measure of the excitability to luminescence of the glass, since the spectral composition of the U.V. radiation is not constant between the current limits. At their low currents the strength of the discharge was 2537Å, whilst at high milliamperages radiations in the range of 3,600Å are of the greatest intensity. This advantage in the emission of U.V. radiation is the main reason why fluorescent-glass is only weakly excited in the high-pressure mercury vapour discharge. The probable explanation is that at low pressure much energy is contained in the electronic and atomic collisions, although they are less frequent than those occurring in a high pressure discharge.

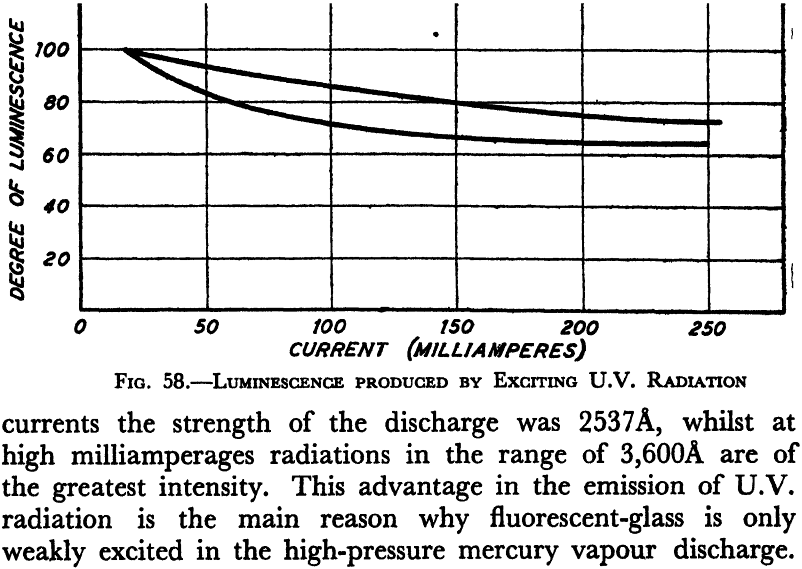


Fig. 58.—Luminescence produced by Exciting U.V. Radiation

The curves, which relate to two differently processed fluorescent-glass tubes, show that if the excitability to luminescence is assumed to be 100% at 15 milliamperes, at 250 milliamperes it still amounts to approximately 70%. The bulk of the 30% decrease is attributed to the change in the U.V. radiation mentioned above, a slight amount being due to decay of the luminescence of the glass wall together with the unavoidable slight heating of the glass.

Transformer Characteristics

The curves in Fig. 59 relate to a typical type of transformer used for operating luminous tubing, with a secondary output of either

10,000 volts at 30 milliamperes or 5,000 volts at 60 milliamperes. A resistance was used as the load in order to obviate the flickering which would have occurred at the lower values if luminous tubing had been used.

It is interesting to note that the maximum efficiency is 88% at 21 to 23 milliamperes which is rather good for a small high-voltage transformer; the value falls off, however, at the operating point of 30 milliamperes.

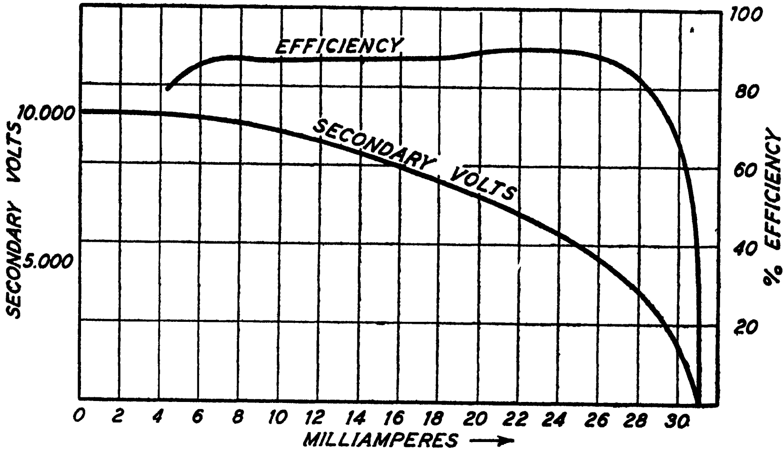


Fig. 59.—Luminous Tube Lighting Transformer Characteristics

Referring to the curve in which secondary volts are plotted against secondary current, it will be seen that the R.M.S. voltage has no consistent relation to the peak voltage. Thus, although a transformer may be loaded with luminous tubing operated at 25 milliamperes with an R.M.S. secondary voltage of about 8,000, it might require peak voltages as high as 15,000 to bring about ionisation of the gases in the tubing on each half-cycle.

Power Factor

Considering the oscillogram in Fig. 60 relating to a luminous tube supplied through a resistance, it is seen that the load is resistive, and the voltage and current are both periodic functions of the time and are non-sinusoidal, yet there is no evidence of reactive power.

This is due to the fact that the resistance of the tube depends on the discharge current, being high for small currents and relatively low for large currents. Actually, the resistance experiences a cyclic variation, describing a complete cycle for every half-wave of current; the effect being similar to that caused by reactance.

Radio Interference

High-voltage luminous tubes are a potential source of interference with broadcast reception. Any noise which does not originate from the transmitting station may be classed as radio interference and, so far as luminous tube installations are concerned, is produced by high-frequency harmonic current.

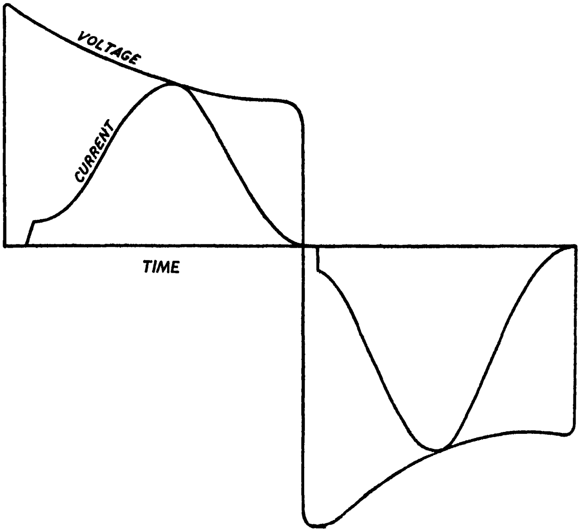


Fig. 60.- -Oscillograms of Current and Voltage for Luminous Tube supplied through a Ballast Resistance

Broadcast interference caused by luminous tubes may be remedied by installing simple filters or low-frequency chokes which, whilst they easily pass a normal 50-cycle supply, stop harmonic currents. Earthed condensers are sometimes installed for dissipation of the interference currents.

Since modern receivers are provided with automatic volume controls to suppress certain signals, location tests cannot always be made with the receiver tuned to a particular station. Usually the best plan is to tune directly to the interference and then disconnect the aerial. If the interference stops or lessens in volume it is definitely established that it is radiated and has not entered by way of the mains supply lead.

Interference caused by a luminous tubing installation may be due to incorrect loading of the transformers or transformer. This means that the tubes are too near "flicker point", thus giving rise to high-frequency distortion. Faults in the transformers themselves are seldom causes of interference.

Before connecting filters it is generally advisable to check the secondary circuit leads and other connections. Sometimes a cable covering or other conductive component comes into contact with the glass envelope, thus setting up a bluish discharge of high frequency. On this account, secondary wiring should always be well spaced from portions of the installation which may tend to excite electrostatic discharge.

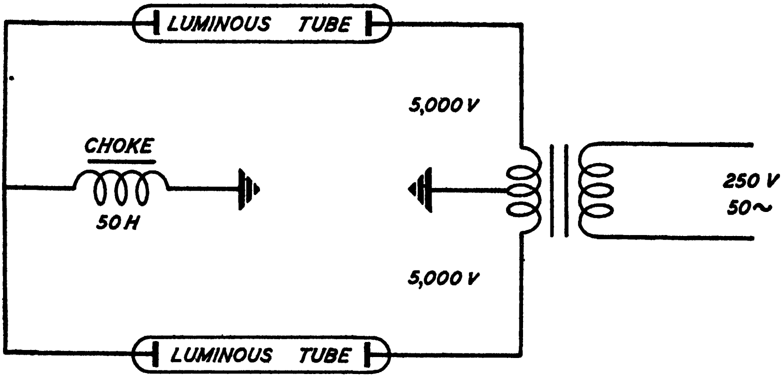


Fig. 61.—Interference Suppression Circuit

Moist or dirty insulators and the proximity of earthed metal or points containing lead or carbon pigments are other potential sources of interference in conjunction with luminous tubes. Also, large differences of potential between adjoining lengths of tubing should be avoided. If it is found that the interference is not traceable to any of the above causes, filters should be included in the circuit.

Too high a self-capacity should be avoided in chokes intended for interference suppression as this may have the effect of bypassing the high-frequency currents. Condensers, when found necessary, should have as small a capacity as possible, remembering that a condenser of ·01 microfarads having a reactance of 1,000 ohms at 50 cycles has a reactance of only 16 ohms at 1 megacycle.

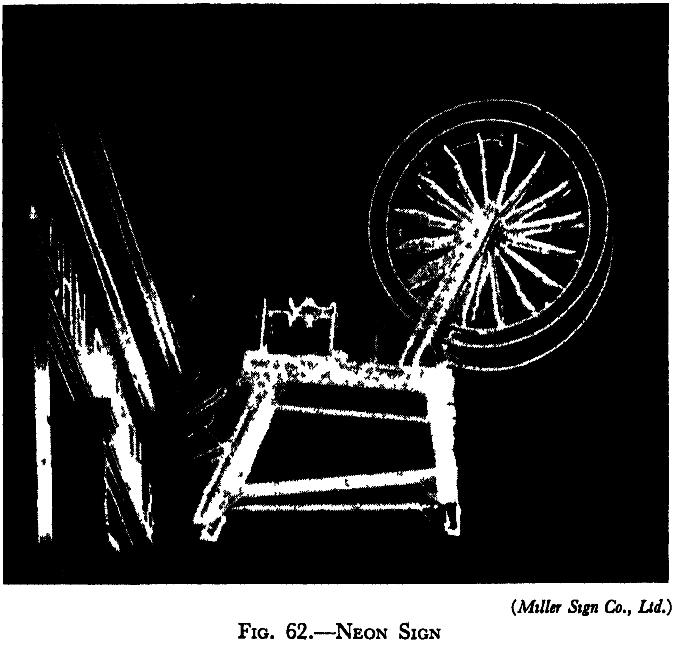
Tests were taken on a small luminous tube installation consisting of 25 feet of neon-filled tubing and 20 feet of argon-with-mercury vapour tubing operated from a 230-volt 50-cycle supply by a transformer with a secondary output of 10,000 volts at 35 milliamperes; the centre points of both transformer and tube circuit being earthed, the interference voltage in microvolts (direct radiation) was 280 on long wave at 210 kilocycles and 25 on medium wave at 1,000 kilocycles.

A 50-henry low-frequency choke was connected in the circuits as shown in Fig. 61, and the readings obtained were 17·5 microvolts on long wave and 3·15 microvolts on medium wave.

Chapter 9

NEON SIGNS

THE production of low pressure luminous tubes was almost completely arrested immediately prior to the outbreak of war in 1939. This was because the principal application of the tubes was in advertising signs to which the "black-out" restrictions spelt annihilation. Nevertheless, the low pressure tube was at that time in process of evolution for many different purposes and it is a great pity that the industry as a whole was allowed to deteriorate.



(Miller Sign Co., Ltd.)

FIG. 62.—NEON SIGN

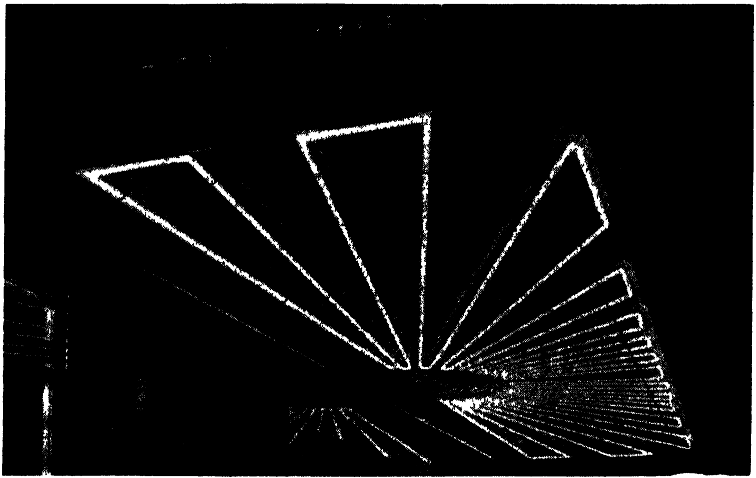
Of its introduction and possibilities as a source of interior lighting mention has already been made, and it would appear that the luminous tube for outdoor illumination—in the shape of neon signs—also comes within the scope of this book.

THE NEON SIGN

Neon signs consist essentially of low pressure cold-cathode luminous tubes bent into the shape of letters, figures or designs and operated (in the United Kingdom) at voltages of up to 10,000, usually from the secondary winding of a step-up transformer.

As a general rule the tubes are internally bombarded whilst connected to the exhaust system by the application of high voltage alternating current to the electrodes. However, there is an alternative method which consists of heating the electrodes by high-frequency eddy currents.

It is of interest to note that the degree of vacuum in a sealed-off tube may be still lowered by a process of electrical clean-up invented by Malignani. In this method a small quantity of red phosphorus, metallic magnesium, calcium, barium or other rare earth metal—known as a "getter"—is previously introduced into the tube and flashed or vaporised by heating. In the case of hot-cathode tubing the filament can be coated with the getter which is thus vaporised as soon as the tube is electrically connected.



(*Claudegen*)

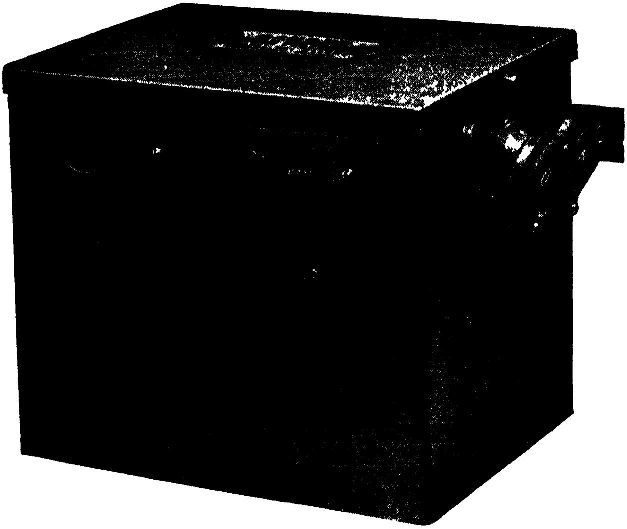
Fig. 63.—Canopy Detail in Neon, London Pavilion

Step-up Transformers

The most suitable type of transformer for neon sign work is the double-wound type enclosed in a metal case with provision for efficient earthing, either oil or air-cooled, for operating tubes at between 35 and 40 milliamperes.

Transformer sizes can therefore be computed by multiplying the current in milliamperes for the particular size of tubing used by the required open circuit or starting voltage.

For instance, supposing we have a small sign consisting of 25 feet of 12 millimetre tubing split up into three sections. At 170 volts per foot run this would amount to 4,250 volts, and assuming each pair of electrodes to have a drop of 250 volts, the total electrode drop would be 750 volts; making a total of 5,000 volts which, when multiplied by the required current output of 25 milliamperes, gives a volt-ampere rating of 125. Taking the required starting voltage to be 10,000, it is obvious that a transformer of ·25 kVA output is necessary.



(Foster Transformers & Switchgear, Ltd.)

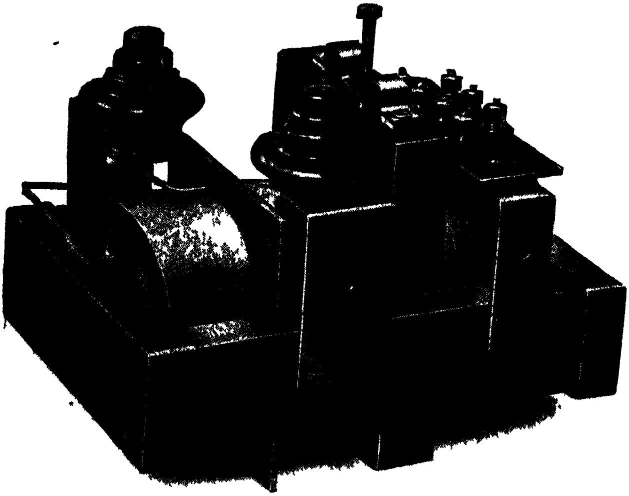
FIG. 64A.—ENCLOSED TYPE NEON TRANSFORMER

Avoidance of Overloading

Overloading may be the cause of many breakdowns, even in portions of a neon sign installation remote from the transformer itself, for the secondary output of an overloaded transformer includes high-frequency harmonics, sometimes in the neighbourhood of 2,000 cycles. It is evident that, on this account, all points of insulation are liable to be subjected to severe strain unless correct loading has been ascertained.

In addition to this effect, when a step-up transformer is operated above its rated output the secondary current will be low and consequently the voltage drop values will be slightly lower than those quoted above.

Blue and green tubes contain a mixture of argon and mercury vapour which has a greater conductivity than neon gas. In general the voltage required for a tube filled with this mixture is roughly two-thirds of that required for a corresponding neon-filled tube.



(Foster Transformers & Switchgear, Ltd.)

FIG. 64B.—NEON TRANSFORMER SHOWING H.T. AND L.T. COILS WITH ADJUSTABLE MAGNETIC SHUNT IN BETWEEN

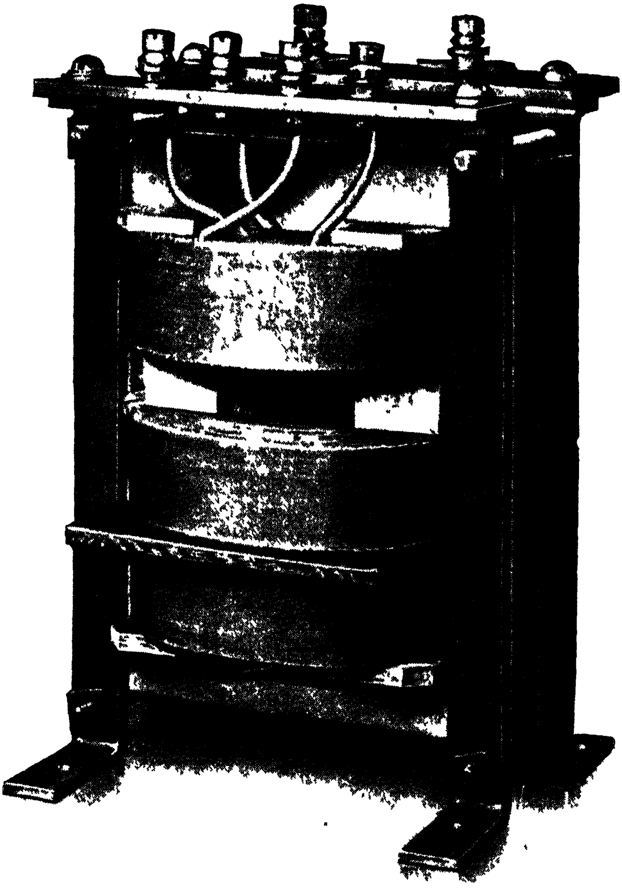
The figures given apply to commercial tubes filled at pressures of from 10 to 18 millimetres with gases of highest purity, since small traces of impurity may affect the resistance considerably.

Transformers for use in conjunction with neon tubes should have an open circuit voltage of approximately twice the calculated running voltage. The voltage necessary under normal operating conditions is much lower than that required for striking up, due to the fact that gases are not conductive until ionised under the influence of an electric field. The difference between the running and starting voltages depends on the diameter of the tube, and varies from 30 per cent for large tubing to 60 per cent in the case of very thin tubing.

Current Outputs

Current outputs are standardised, being determined largely by the diameter of the glass tubing; 12 millimetre tubes are generally operated at 20/25 milliamperes, oil or compound filled transformers are permissible.

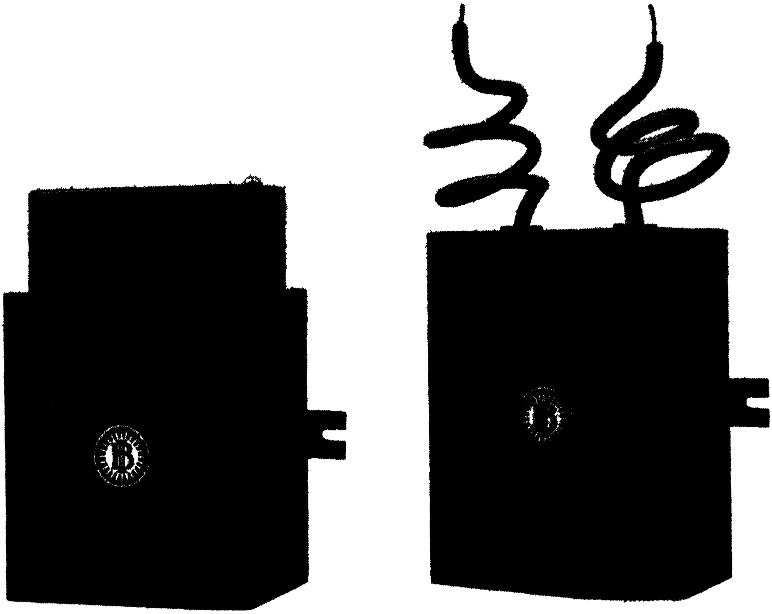
Since the voltage on the secondary side (to earth) should not exceed 5,000, it is customary for the secondary windings of the larger transformers to be split and the middle points earthed. Thus the maximum difference of potential between the two high tension terminals amounts to 10,000 volts on open circuit. The current output (upon which the brilliancy of the sign depends) is usually from 25 to 35 milliamperes.



(Foster Transformers & Switchgear, Ltd.)
Fig. 64c.—Open Type Neon Transformer

Regulation is provided by means of small adjustable high tension chokes which are generally contained in the transformer itself and fitted with clamps so that the desired current output can be maintained.

In calculating the size of transformer required for a particular sign or section of luminous tubing, four main factors have to be taken into consideration. They are: (1) the total length of tubing; (2) its diameter; (3) the electrode drop; and (4) the colour of the discharge or variety of rare gas with which the tube is filled.



(British Insulated Cables, Ltd.)

FIG. 65.—POWER FACTOR CORRECTION CONDENSERS

Required Voltage

The voltage necessary to operate a neon-filled tube (i.e., glowing red) of 12 millimetres diameter is approximately 170 volts per foot run, and the electrode drop varies from 250 to 400 volts per pair according to the surface area and material of which they consist.

Tubes of larger diameter have less resistance.

Power Factor Correction

Since neon sign transformers are designed with poor regulation on account of the excess of striking voltages over running voltages, their power factor is low (generally between ·4 and ·6). It is necessary, therefore, to take a power factor test and provide for correction or improvement to ·8 by means of static condensers. Condensers, as used for this purpose, consume practically no energy apart from the losses—usually about ·3 watt per kVA. —and require absolutely no attention subsequent to their installation.

In cases where a sign is operated by more than one transformer, it is generally more economical to instal one condenser of sufficiently large capacity to correct the whole installation than to correct each individual transformer. A condenser of, say, 50 microfarads capacity can be purchased for less than two 25-microfarad condensers.

One disadvantage of this method, however, is that it often necessitates the condenser being situated at some distance from the transformers and some method has to be provided for its disconnection and automatic discharge. It is therefore essential to fix a high resistance leak across the condenser terminals and in some cases to include a separate switch.

Since the power factor of a neon sign may be taken as the simple ratio of watts to the product of volts and amperes, the calculation presents no difficulty. Having determined the power factor, it then remains to work out the size of condenser or condensers which will be required for correction to ·8.

The compensation of watt-less component in terms of the initial kVA. of a sign is given by the following formula:

$$\text{Corrective kVA. necessary} = \sqrt{(1 - A^2)} - \frac{A}{B}\sqrt{(1 - B^2)} \times$$

100% of initial (uncorrected) kVA; where A is the power factor of the sign, and B is the value to which it must be improved.

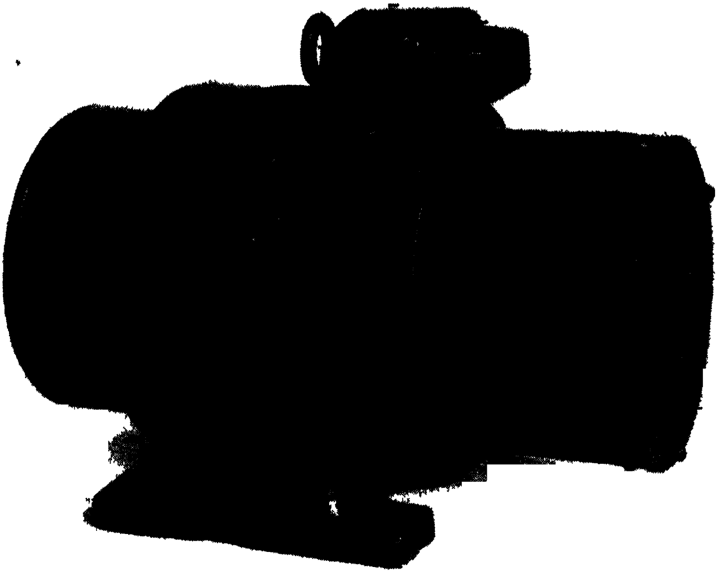
For conversion into capacity in microfarads, the result should be multiplied by $\frac{10^9}{2\pi f e^2}$ in which f = frequency in cycles per second and e = voltage applied.

It is important to remember that a great deal depends on the voltage and frequency of the supply concerned.

For instance, a condenser rated at 25 microfarads on 230-volt circuits will not have the same value of capacitance if used in connection with a 110-volt supply. Evidence of this fact is given when we consider that a load of one kVA. on 230 volts requires approximately 25 microfarads to correct the power factor from

·55 to ·8, but this load on a 110-volt circuit would need 112 microfarads to provide the same correction.

Another point to remember is that required capacity increases as frequency decreases, and it is rarely advisable to use condensers for power factor improvement in systems of lower frequency than 50 cycles per second.



(*Lancs. Dynamo & Crypto, Ltd.*)

FIG. 66.—TYPICAL 3 kVA., 3,000 R.P.M. NEON SIGN ROTARY CONVERTER

Rotary Converters

In cases where neon signs are to be installed in districts where direct current supply only is available, three alternative methods of conversion to alternating current present themselves. They are the installing of: (1) rotary converters; (2) vibrating reed interruptors, or (3) inverters. The second alternative, however, has certain fundamental drawbacks when applied to neon sign operation.

Neon sign rotary converters are almost invariably of the single-phase type with kVA. outputs of ·16 to 15. The speed of the smaller sizes is usually 3,000 r.p.m., whilst machines of comparatively large outputs run at about half of this speed.

When installing, the rotary converter should be mounted on a solid foundation in as cool and accessible a position as possible. In some situations it may be found necessary to fit a layer of rubber under the base in order to lessen the noise from vibration.

It should be noted that according to I.E.E. Regulation 804D the primary transformer circuits can be permanently earthed at the converter.

Since the input in the case of a rotary converter for use in conjunction with a neon sign is D.C., the starting presents no difficulty.

For supplies up to 250 volts, it is permissible to switch the converter direct on the line provided that the rated output does not exceed 1 kVA. In practice, however, a starter is recommended on all machines above ·75 kVA.

A double-pole circuit breaker fitted with a combined overload and inverse time limit trip and magnetic blow-out coils may be used to switch the smaller size converters direct on the line. These are preferable to the ordinary switch-fuse, although they are naturally more expensive.

Automatic starters may be used in conjunction with 3-wire "start" and "stop" push-buttons, time switches or other methods of remote control. A single-pole contactor will suffice for converter outputs up to about ·5 kVA., but above this two, four or five-step starters, for loads as recommended by individual makers, should be installed.

In all cases where a starter is installed, a double-pole switch must be included.

Inverters

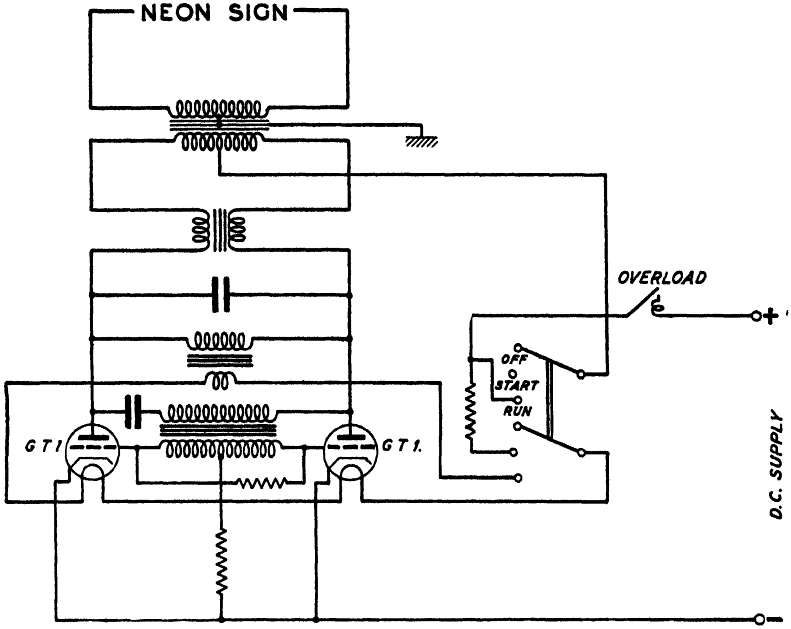
The advantages of using an inverter to supply a neon sign are the comparatively low initial cost and elimination of all mechanical noise liable to set up interference. Practically no servicing is necessary apart from occasional replacement of valves, which can easily be carried out by the layman, and, taking into consideration the fact that the life of such valves is usually over 2,000 hours, this item is indeed a small one.

An inverter is entirely a static apparatus and consists essentially of a highly efficient valve oscillator incorporating gas-filled relays. The relay comprises a mercury vapour discharge tube with grid control (indirectly heated cathode) and the main precaution to observe when operating is to allow time for the cathode to attain its full operating temperature before applying the anode voltage.

The arrangement shown in Fig. 67 employs two Osram G.T.1

gas-filled relays, and when operated from a 230-volt supply is sufficient for approximately 25 feet of 12 millimetre diameter neon tubing, the efficiency of conversion being 65 per cent.

Since the wave-form of the output voltage from this type of inverter is not sinusoidal but almost rectangular in shape, the light from the neon tubing is uniform over a considerable portion of the cycle. Hence there is theoretically less flicker from signs operated in this manner than from transformer-operated signs.



(G.E.C. Ltd.)

FIG. 67.—SIMPLIFIED CIRCUIT DIAGRAM OF INVERTER EMPLOYING OSRAM G.T.1 GAS-FILLED RELAYS

"Uneon" System

Low-pressure cold-cathode discharge tubes as used for A.C. neon sign installations are as stated earlier, usually operated by step-up transformers giving secondary outputs of between 20 and 50 milliamperes at from 5,000 to 10,000 volts. These transformers are deliberately designed to have a high reactance and poor regulation, which involves large magnetising currents. Thus, the efficiency is somewhat low and the power factor poor.

A system of choke feed has been developed by which the inefficient transformer is dispensed with. The circuit used, known as the "Uneon" system is shown in Fig. 68.

A variable inductance choke is connected to the mains via a large condenser so that the circuit may be tuned to resonance, thus resulting in a potential of several thousand volts being developed. The neon tubes are then connected across the high tension leads, each tube unit being in series with a condenser and choke to limit the current after striking by reducing the voltage as soon as the discharge has been set up.

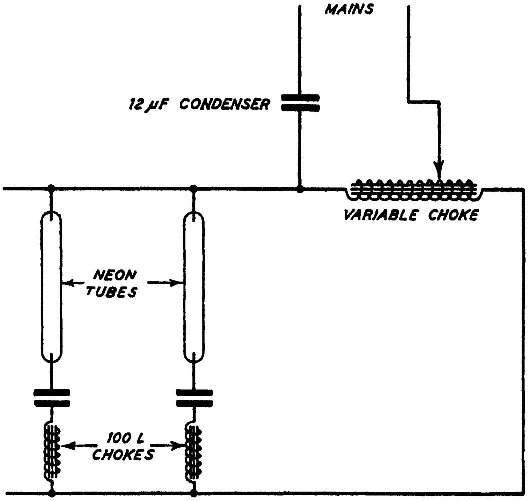


Fig. 68.—Uneon System

The number of neon tubes that can be connected to the system is, of course, dependent on the limits of the resonator, although each tube unit operates quite independently of the others. Tubes of various lengths can therefore be included without in any way upsetting the circuit.

"Uneon" systems are particularly suitable for supplying interchangeable letter signs for use outside cinemas and cafés.

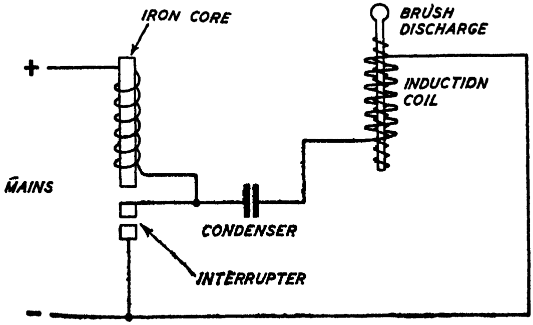


Fig. 69.—Tesla Coil

Tesla Coils

Fig. 69 shows an apparatus which is sometimes used for operating low-pressure hot-cathode luminous tubes from direct current supplies; the diagram here is self-explanatory.

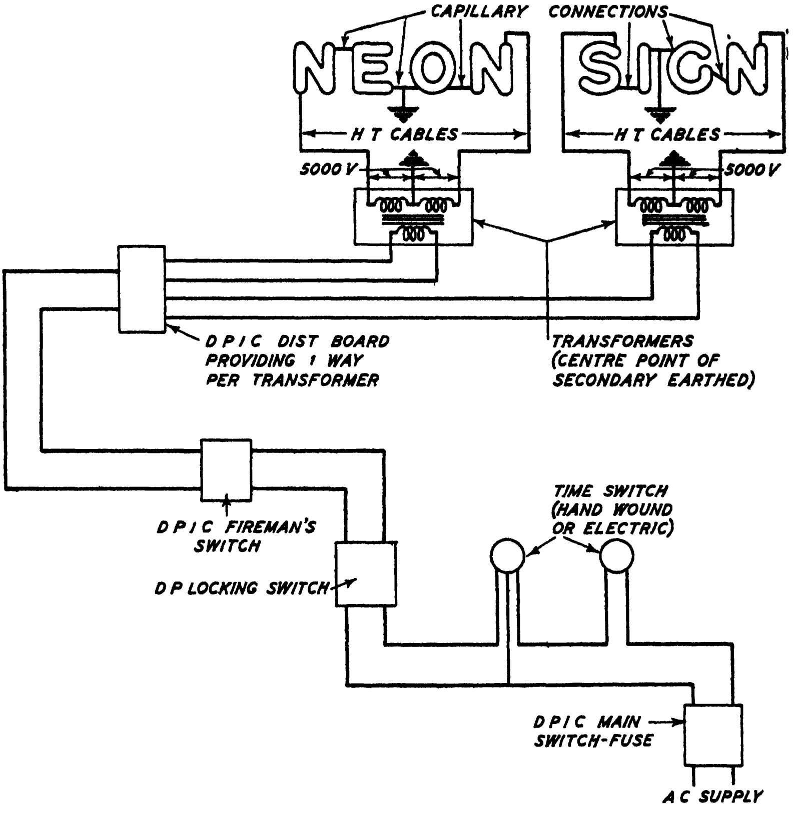


Fig. 70.—Typical Arrangement of a Neon Sign Installation

Maintenance of Neon Signs

Apart from breakage of the glass or failures due to material defects, a properly installed neon sign needs very little attention. Particular care is necessary, when first installing the sign, in making the series connections between the electrodes of adjoining letters or tube sections, as considerable damage may be caused by neglect in this respect. This applies to all high tension housings, bell glasses and capillary tubing (see Fig. 72).

Breakage of glass insulators through which bare wire has been run is far too common a source of breakdown. Service calls traced to this cause usually occur after heavy gales, when it is found that the glass insulation has been insecure in the first place and the wind has done the rest.

When the electrodes pass through holes drilled in wood letters or backgrounds it is sometimes found that failure has been due to water lodging in the cavities, thus setting up abnormal stress. Similarly, deposits of dirt on portions close to the H.T. connections can have almost the same effect.

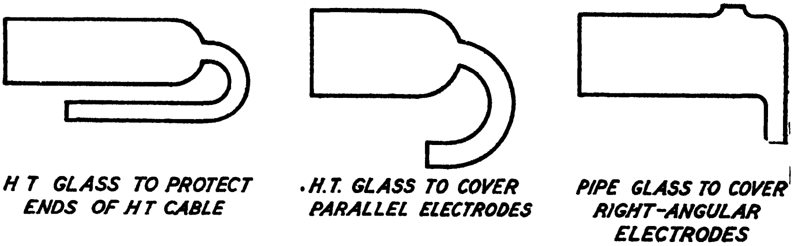

H T GLASS TO PROTECT ENDS OF H T CABLE
H.T. GLASS TO COVER PARALLEL ELECTRODES
PIPE GLASS TO COVER RIGHT-ANGULAR ELECTRODES

FIG. 71.—TYPES OF GLASS INSULATORS

In a straightforward neon sign installation (i.e., without animation or special effects) transformer failures are mostly the result of: (1) insufficient protection from the weather when installed outside; or (2) incorrect loading.

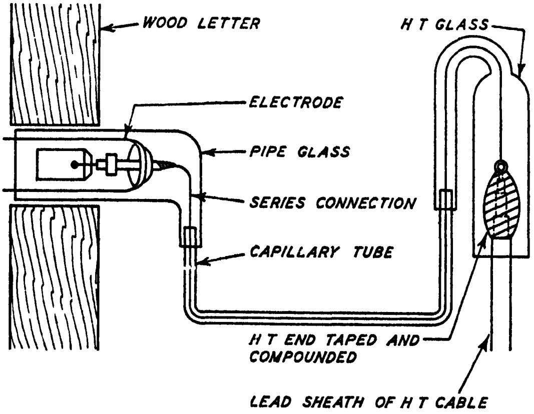


FIG. 72.—CONNECTION BETWEEN CABLE AND ELECTRODE

With regard to the first point, prevention rests in choosing transformers which are capable of withstanding the most rigorous weather conditions. These are generally encased in heavy steel welded non-rusting galvanised cases and provided with cast entry sockets for high-tension cable.

Correct loading is an important item from a maintenance point of view; many cases of breakdown are due to failure to allow a margin. As a rule, the primaries of neon sign transformers are tapped and brought out to terminals for the usual supply voltages. Sometimes it is found that when the low tension wiring is connected to the correct terminals a transformer will not operate the desired load.

For instance, supposing the transformer is required to operate 30 feet of neon tubing on a supply at 230 volts 50 cycles. In practice, the tubes may not be steady on the 230-volt terminals, but may be quite satisfactory when the 200-volt tapping is used. If left on the lower voltage terminals, the transformer will be over-run, and will be liable to breakdown.

There is yet another reason why a larger transformer should be used in the above case. That is, that during the life of a neon sign the tubes become "hardened" or, in other words, their resistance is increased. Thus, after a certain period of use they begin to flicker unless a margin or some means of adjustment of the high tension supply has been provided.

Sometimes the neon gas inside a letter or section of tube "fails" or escapes due to a crack in the glass or other defect. This usually puts out the whole circuit with which it is connected in series. Then the job of locating the faulty section begins.

The usual procedure at this stage consists in shorting out each letter or section in turn until the remainder of the sign lights up when switched on. If two or more letters are faulty, however, the process may become rather complicated, so that a systematic examination of the tubes and connections beforehand is always advisable.

When the guarantee has expired (and all manufacturers of repute give a guarantee), the neon sign user can be assured of the continued efficiency of his sign in the future by entering into a maintenance agreement with the contractor.

A popular form of contract provides for an electrician to pay periodical visits to the sign during each of which a milliampere test of secondary circuits is taken, and all H.T. connections are examined. Any of the latter that appear to be insecure are renewed—similarly cracked bell-glasses and housings are replaced.

It is most advisable that the signs should be regularly and thoroughly cleaned. This is important not only from the point of view of appearance but from an electrical standpoint also, for dirt causes a considerable amount of high tension leakage.

On each occasion whilst a neon sign is being inspected, tested or cleaned, the maintenance electrician should withdraw the key from the locking switch and keep it in his possession until he has finished his job.

When neon sign users reside on the premises in connection with which the sign is erected, the maintenance engineer occasionally receives complaints that the wireless reception has been affected.

In most cases this can be suppressed by inserting a choke of about 50 henries inductance, but if the supply is obtained through a rotary converter it may be necessary to fit two condensers (see Fig. 73). One terminal of each condenser should be earthed and the remaining two connected across the arcing contacts; the value of the condensers can only be ascertained by experiment.

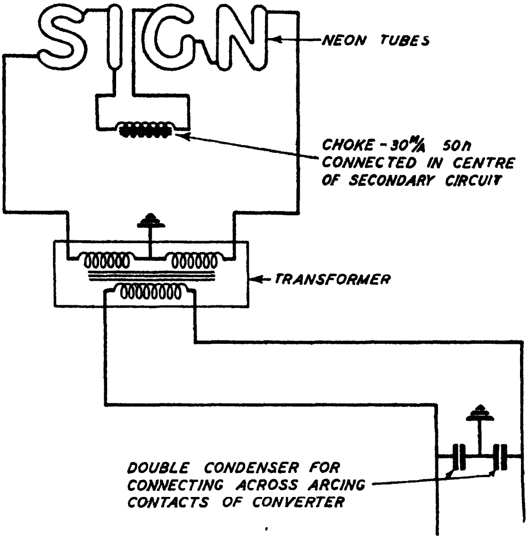


Fig. 73.—Suppression of Radio Interference at Source

When dealing with complaints of this description, the installation should be examined for loose H.T. connections or other faults liable to set up static distortion.

Under-bombardment or failure to exclude all impurities before finally gassing neon tubing lessens its life considerably and results in loss of colour and luminosity during the period of its use.

The extraneous gases usually present during bombardment consist of hydrogen and carbon monoxide with traces of nitrogen, and since the conductivity of these is not so high as that of the rare gases, the under-bombarded tube will probably require a current considerably in excess of that normally applied.

Another cause of short life in a tube may be attributed to faulty glass-blowing or careless handling of the section by those erecting the sign. This often results in the formation of tiny star-cracks, which, although they may not be sufficient to effect immediate alteration in internal pressure, form, as it were, a "weak link in the chain" and are liable to enlarge with changes of atmospheric temperature.

It is always worth while to pay particular attention to the arrangement of clip-supports for fastening the glass to wood letters or other backgrounds, as it is this operation that decides whether a section will be normally secure or under permanent stress.

Hence we may conclude that, apart from breakage, the life of a neon sign depends almost entirely on the quality of the materials and workmanship, since the decrease in gas pressure due to electronic causation is so slight as to be disregarded under present-day standards.

Animating Neon Signs

Sign animation has, apart from the war interlude, occupied the attention of technicians for some years past. It is by no means a new art. Since the introduction of the metal filament lamp hundreds of variations of the animated effect have been evolved. But many of the problems in connection with the flashing of neon tubes are as yet unsolved and in some cases lamps of the sign filament type have been installed in conjunction with a neon sign in order to give the best effect from an animation point of view.

It is, perhaps, advisable to discriminate between "animation" and "spelling". Strictly speaking, animation is an illusion of movement given to an inanimate device. Spelling a name, letter by letter, cannot be said to produce any illusion, and therefore cannot be called a form of animation.

One disadvantage of neon tubes insofar as animation is concerned, is their relatively high value of "nigression" or afterglow. This is due to the fact that the discharge in a gas-filled luminous tube ceases immediately the current is switched off. For realistic effects at slow speed, a certain amount of nigression is necessary in order to convey a smooth continuity of movement to the eye. This disadvantage is offset by employing fluorescent tubing.

Running borders and similar effects are often animated by low-tension flashers. The border or other device is made up of short lengths of neon tubing, which are coupled up in chasers and operated by individual transformers.

In this case, the principle is very much the same as that of an animated filament lamp sign except that the flasher connections are made to the transformer primary terminals instead of to the lamp circuits.

As the voltage required to strike up the discharge in a neon tube is considerably higher than the operating voltage, transformers that have to stand up to the constant rushes of current required for animation must be of very robust construction.

Insofar as the I.E.E. Regulations are concerned, a motor employed for flashing a luminous tube sign (unless transportable) must be connected to an independent final sub-circuit.

When the flashing is taking place on the high-tension side of the transformer, it follows that, normally, the primary circuit will remain unbroken, and at every "all off" period the transformer will be open-circuited. This may be obviated by connecting permanently a length of neon tubing which need not form part of the display.

High-tension flashers of the arc gap type, introduced comparatively recently, are quite suitable for small animation effects. The apparatus is driven by a low-speed motor of the eddy current disc type, provided with a method of speed variation. In its action, the flasher itself is similar to that of the spark distributor of a motor-car.

Mercury-switch flashers are very satisfactory for neon sign work, and can be made up in almost any number of ways. The drive (assuming that the supply is A.C.) is supplied by an induction motor with speed control by centrifugal governor.

The actual make and break is due to mercury switches operated by a rocking mechanism. Mercury switches are very reliable and definite, so that the possibility of radio interference from this type of flasher is reduced to a minimum. There is usually a vernier adjustment for synchronising circuits.

For simplicity, the main connection is through a bus-bar, and it is fused in each sign circuit.

The question as to which of the two methods of flashing—high tension or low tension—is the more economical is rather a difficult one. Wiring and connections for the latter can be carried out in ordinary cable, but in the former case high-tension cable, which is considerably more expensive, must be used.

On the other hand, the low tension flasher requires a transformer for each way, whilst only one is usually necessary for the other. To a great extent the answer to the questions depends on the particular characteristics of the sign required to be animated.

It is occasionally found that one end of a tubing unit in a neon sign controlled by a flasher will glow even when the sign is "off". This is caused by the capacity of the flasher contacts, which admits a small current to the electrodes. Provided that the glow is weak, it may be neglected, but otherwise it is advisable to overhaul the flasher.

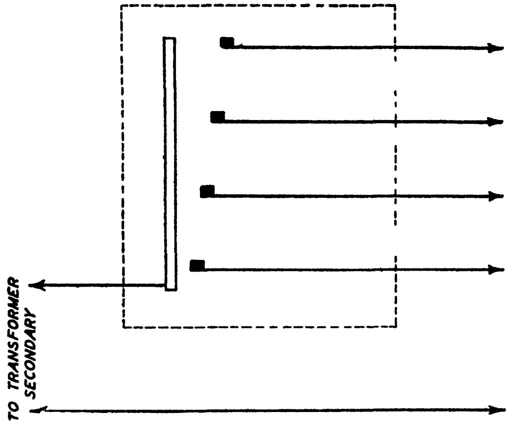


FIG. 74.—PRINCIPLE OF HIGH TENSION SPARK-GAP FLASHER

In some types of high-voltage flashers an arc is produced between the contact points as each tubing section is connected in the circuit. This arcing produces ozone, which, combining with the nitrogen and moisture in the atmosphere, is converted into nitric acid. The acid, even in dilute form, is injurious to both metal and insulation. Protection from corrosion can be obtained by applying a coat of asphalt paint to all parts liable to be affected.

Sometimes, the effect which a sign is called upon to produce can be best achieved by dimming. The most common method of dimming neon tubes is by connecting an arrangement of chokes in the circuit.

A novel method of producing the same result has been evolved in the United States. Essentially, it consists of a dual-transformer so connected that one-half can oppose the other.

The primary winding is connected in series with a variable resistance, across the ends of which a condenser is shunted. By varying the resistance the primary circuit may be regulated and the secondary will act as a resistance in series with the luminous tubes.

Photo-Electric Control

A photo-electric cell may be described as a device capable of converting light into an electric current. In its action the cell bears a strong resemblance to the thermionic valve, and can respond faithfully to light variations up to a very high frequency.

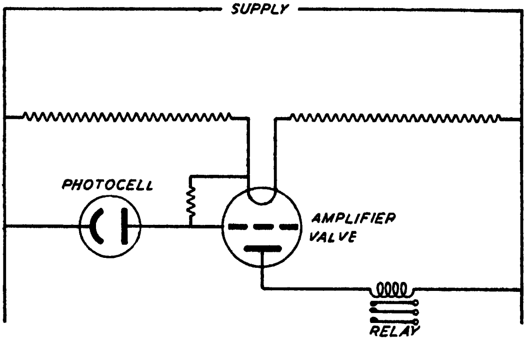


FIG. 75.—TYPICAL PHOTO-ELECTRIC AMPLIFYING CIRCUIT

For neon sign control on alternating current systems, the essential components for a photo-electric relay are a tapped transformer, a sensitive relay, a small contactor, a photo-electric cell, and an amplifier valve. Normally, the contactor is set to close at nightfall, but a small change-over switch is usually provided to suit special conditions.

The range of adjustment for a unit required to control loads of up to about 2 kilowatts is generally from ·2 to 10 foot-candles, and the power consumption will probably be approximately 15 watts with the contactor closed and 8 watts with the contactor de-energised. A typical amplifying circuit is shown in Fig. 75.

From a replacement point of view, the photo-electric relay is quite satisfactory; the life of a photo-cell and valve on test having been estimated to be over 17,000 hours.

When used for controlling D.C. circuits an external resistance box must be connected to the unit, which increases the power consumption considerably (generally to about 200 watts).

It sometimes happens that an outdoor neon sign is not sufficiently effective in broad daylight to justify continuous burning. Yet there are certain periods at all times of the year during which such a sign can be illuminated to advantage in the daytime. Thus the advertiser is faced with two unsatisfactory alternatives—either to have a time-switch installed for cutting out the sign during the daytime, or to arrange for constant illumination regardless of visibility.

In cases where the latter method has been adopted photo-electric relays can effect a saving in both current consumption and in the useful life of the neon tubes.

The unit, comprising photo-cell, amplifier, contactor and relay, is fixed in an exposed position and connected to the sign circuit. Thus, whenever the daylight falls below a stipulated minimum the photo-cell will close the contacts and bring the sign into operation.

One of the many potential applications of the photo-cell as an advertising novelty is the following. A mirror is hung at a convenient height in the lobby or waiting-room of a cinema. Directly underneath the mirror is a recess containing programmes or leaflets advertising forthcoming attractions.

When the lady patron stops to adjust her hat, she catches sight of a notice painted at the bottom of the mirror which asks her to take a leaflet. As she puts her hand into the recess in order to comply with this request, she breaks the light ray which is focused across the recess entrance on to a photo-electric cell. This actuates the relay, which, in turn, causes the mirror to be illuminated by neon tubes at the back, thereby displaying an announcement of a coming film.

For hotels and garages, particularly those situated near main roads, neon signs operated in conjunction with photo-electric relays can be installed to advantage.

In this case the photo-cell unit is fixed in such a position that it will be actuated at night by the headlights of approaching vehicles, and will thus switch on the sign. By this means the sign can be illuminated for perhaps a hundred yards before a car reaches it, so that the driver or occupants can hardly fail to observe it.

The necessary distance of the car from the relay to cause the sign to light up will, of course, depend on the power of the headlights and the sensitivity of the photo-cell.

Similarly, signs erected adjacent to a railway line can be put into operation by interruption of the light beam directed on a photo-electric cell by passing trains. By means of a time delay switch (see Fig. 76), the sign can remain on for a predetermined period, so that it can be seen by passengers throughout the length of the train.

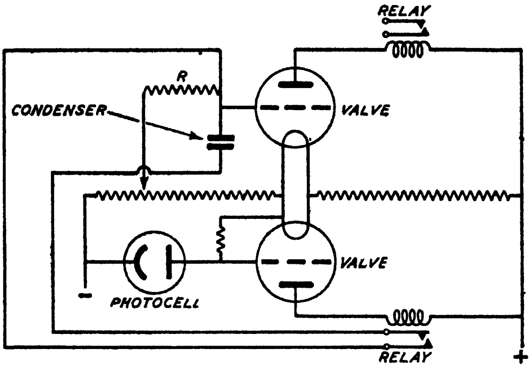


FIG. 76.—SIGN CONTROL UNIT INCORPORATING TIME DELAY

Useful Data for Neon Sign Installations

INSTALLATION NOTES

(1) Bare wire used for series connections between adjacent sections of a neon sign:
  (*a*) shall not exceed 18 inches in length;
  (*b*) shall be carried in glass tubing with a minimum wall thickness of 1 millimetre and an overall diameter of from 5 to 7 millimetres.

(2) Metallic covering of high-tension cables and armouring (if any) must be stripped back beyond the insulation for a distance in inches of not less than 2·5 divided by the number of kilovolts to earth of the open-circuit secondary voltage R.M.S. of the transformer.

(3) A separate primary final sub-circuit should be provided for each transformer with an input of 250 volt-amperes or more.

(4) Transformers with an input of below 250 volt-amperes may be grouped, but the aggregate input must not exceed 1,000 volt-amperes.

(5) Fireman's switch to be fixed not more than 9 feet above the ground.

(6) Double-pole locking switch should be provided to control each primary final sub-circuit.

(7) Warning notices must be fixed at all points of access to tubes and high-tension apparatus.

APPROXIMATE VOLTAGE DROP PER FOOT

Colour.	Millimetres diameter. 10–12 (25 m/a.)	 14–16 (35 m/a.)	 20–22 (60 m/a.)
Blue or Green	135	95	85
Red ..	175	120	110
White or Gold ..	370	260	220

MAXIMUM SPACING OF SUPPORTS FOR HIGH TENSION CABLES WHICH ARE NOT METAL SHEATHED

Cable Run.	Maximum Spacing of Supports.
Horizontal	1 foot 6 inches
Vertical	2 feet 6 inches

MAXIMUM SPACING OF SUPPORTS FOR METAL SHEATHED HIGH TENSION CABLES (UNARMOURED)

Cable Run.	Max. R.M.S. Voltage to Earth.	Max. Spacing of Supports.
Horizontal	Up to and including 6,000	2 feet 6 inches
Horizontal	Above 6,000	2 feet
Vertical	Up to and including 6,000	4 feet
Vertical	Above 6,000	3 feet 6 inches

MAXIMUM SPACING OF SUPPORTS FOR METAL SHEATHED HIGH TENSION CABLES (ARMOURED)

Cable Run.	Max. R.M.S. Voltage to Earth.	Max. Spacing of Supports.
Horizontal	Up to and including 6,000	3 feet
Horizontal	Above 6,000	2 feet 6 inches
Vertical	Up to and including 6,000	5 feet
Vertical	Above 6,000	4 feet 6 inches

COMPARISON OF CATHODE DROP IN THREE GASES

Metal.	Neon.	Helium.	Argon.
Aluminium ..	120	165	145
Copper	210	170	150
Iron	153	161	166
Magnesium ..	122	126	150
Potassium ..	68	69	71
Sodium ..	75	80	73

PROPORTIONAL INCREASE IN CURRENT WITH INCREASING DIAMETER OF TUBING WHEN THE SAME CURRENT DENSITY IS REQUIRED

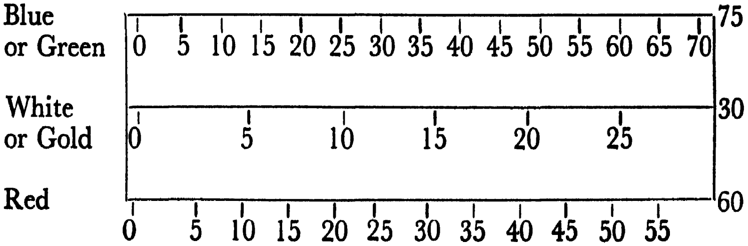
Diameter of Glass Tube in Millimetres.	Milliamps.	Milliamps.	Milliamps.
5	4	5	6
10	15	20	25
15	35	45	55
20	60	80	100
30	135	180	225
45	300	400	500

APPROXIMATE TUBE FOOTAGE WHICH CAN USUALLY BE OPERATED BY STANDARD TYPES OF NEON SIGN TRANSFORMERS

Kilo-volts.	Milli-amps.	10 mm.		12 mm.		15 mm.		20 mm.	
		Red	Blue or Green	Red	Blue or Green	Red	Blue or Green	Red	Blue or Green
3·5	30	8	10	10	12	11	14	—	—
4·0	40	—	16	—	17	—	18	—	—
5·0	30	13	—	14	—	15	—	—	—
6·0	40	—	21	—	22	—	25	—	—
7·0	30	18	—	19	—	21	—	—	—
8·0	40	—	32	—	34	—	36	—	—
10·0	30	28	—	29	—	31	—	—	—
10·0	60	—	—	—	—	—	—	40	50

The chart below is used for calculating load requirements and transformer selection for neon sign installations in which it is found necessary to operate tubing of more than one colour from the same transformer.

Example.—It is desired to run 25 feet of blue tubing in conjunction with 10 feet of red tubing. By applying a ruler vertically to the chart it is found that 25 feet of blue tubing is equivalent to 21·5 feet of red. Thus, a transformer which will operate 31·5 feet of red tubing is required.



Chapter 10

MISCELLANEOUS

To attempt a description of *all* commercial possibilities of the luminous discharge tube would be a very difficult task indeed, as they are so numerous and varied. The history of discharge tube development and application indicates that there is an increasing demand for devices utilising the principle of ionisation and, although a great many of these are, as yet, in the experimental stage, there are some appliances of comparatively recent introduction that have been tested and found satisfactory and which are decidedly on the market.

High Intensity Tubes

Neon signs consisting of small diameter fluorescent tubing operated at high current densities were, in 1939, gaining some popularity, especially for small displays. Naturally, signs constructed of this "high intensity tubing", which is generally about 7 or 8 millimetres in diameter, are fairly high in transformer cost due to the comparatively large current outputs required. However, lettering double-outlined with this type of luminous tubing is extremely legible as compared with ordinary neon tubing when viewed at a distance, since the reduction in irradiation due to the small diameter is greater than the increase afforded by the additional current density.

Ripple Tubes

These are large diameter blue or green luminous tubes, into which traces of impurity are deliberately introduced in order to give a discharge of irregular path. They are usually made up in circles as novelty displays, and the effect produced is that of a continuous rippling movement.

Aerial Beacons

The high efficiency of neon tubing in the red range, and its extreme power of penetration, make it ideal for this purpose.

Beacons are generally constructed of large diameter tubing provided with high-current hot cathodes, and the light is produced by an arc discharge as distinct from the glow discharge of a neon sign. Currents of one ampere or more are used to give the necessary brilliance, and the tubes are, of course, arranged to give the maximum concentration of light.

It is claimed that some of these neon beacons can be seen for distances of as much as 100 miles.

The Neon Fuse

Since the potential difference required to ionise the rare gas and set up the discharge in a neon tube is greatly in excess of that required to continue the discharge, the tube can be used in high-voltage systems as a protective device for connection across sensitive meters.

Normally, there is no glow in the tube when inserted as a fuse, but if a high-voltage surge occurs, a discharge is set up and the voltage across the electrodes immediately falls to a safe value.

In addition to providing a safety measure, the tube acts as a signal, for when the glow is present the operator knows that some adjustment is necessary.

A.V.C. Indicator

This consists of a neon-filled tube containing two short electrodes and one long one.

It is used in radio receivers fitted with automatic volume control to give a visual indication of the correct tuning point, at which stage the glow is of maximum length.

A voltage of from 165 to 180 is required between anode and main cathode, and the current necessary to produce the glow varies from ·15 to 1·4 milliamperes, the length of the luminous column depending, of course, on the exact value.

Grid-Glow Control Tube

Familiarly known as a gas-filled relay, this device consists essentially of a mercury vapour discharge tube in which the electron emission is obtained from a coated cathode enclosing a heater of approximately 5 watts input.

It is used as a rheostatic voltage regulator, and finds an application in theatre dimming. One of the fairly recent developments is the use of the tube for control of inverters. Other serviceable applications are provided by employing the contrivance as a simple relay and in conjunction with a photo-electric cell.

Under normal operating conditions there is a bluish glow present in the tube, due to the ionisation of the mercury vapour, and the voltage remains constant at about 15 volts independent of the load. The anode voltage must not be applied until the cathode has been allowed time to attain its full temperature.

Television

The Baird system of television requires for reception a lamp that will respond in light intensity to rapid current fluctuations, and here again the neon tube supplies the need.

Neon lamps for television are of three types—the plate type, the crater type, and the positive column type—each having its own particular advantages and disadvantages.

Originally, a voltage of at least 600 was required to operate the lamps, but research reduced this considerably, and neon tubes are now being made with a striking potential of 170 volts.

They must be coupled up by means of a choke, but will operate quite satisfactorily from super power valves and may be run off an eliminator.

Plant Irradiators

The light from neon tubes has been found to accelerate the growth of plants and flowers, and units known as "Irradiators" are now being manufactured. It is said that the result of installing the apparatus in a greenhouse is not only the yielding of far more abundant crops of fruit, but the imparting of an additional flavour and sweetness usually absent from forced fruits.

Irradiators are supplied for use on 230 volt and 400 volt A.C. supply systems and with rated current consumptions of between 1 and 5 amperes. The most important factor to take into consideration when choosing is, naturally, the light intensity of the neon tube, upon which depends the area of surface irradiated.

Production of Oscillations

In a luminous discharge tube the initial discharge is continued down to some lower potential, owing to increasing frequency of ionisation. This effect is due to charges in the pre-existing electric fields and is of great importance, for it is thus possible to generate oscillations.

If a condenser C can be connected in parallel with a discharge tube D and in series with a resistance R as shown in Fig. 77 with a source of e.m.f. E, and a key K, the current through the tube will proceed round the hysteresis loop once each cycle.

In operation, K is depressed and C becomes charged until the potential difference between the plates reaches the sparking potential of the tube after which the discharge strikes up. As the condenser voltage decreases the discharge eventually ceases then begins to build up with rise of plate potential and the process is again repeated.

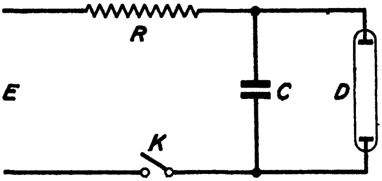


FIG. 77.—PRODUCTION OF OSCILLATIONS

If the time of discharge is small compared with the time required for recharging of the condenser, the periodic time of the oscillation is:

$$C R \log (E - V_b)/(E - V_c)$$

in which E is the applied e.m.f. and V_c and V_b are the sparking and extinction potentials respectively of the tube.

A range of oscillations varying between radio frequency and one discharge every half-minute can be obtained in this way.

Tungsten Mercury Arc

Whilst not, strictly speaking, a luminous tube the tungsten mercury arc lamp, shown in Fig. 78, is a special application of an arc discharge.

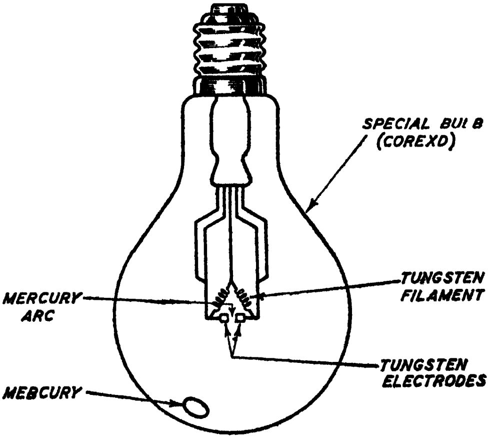


FIG. 78.—TUNGSTEN MERCURY ARC

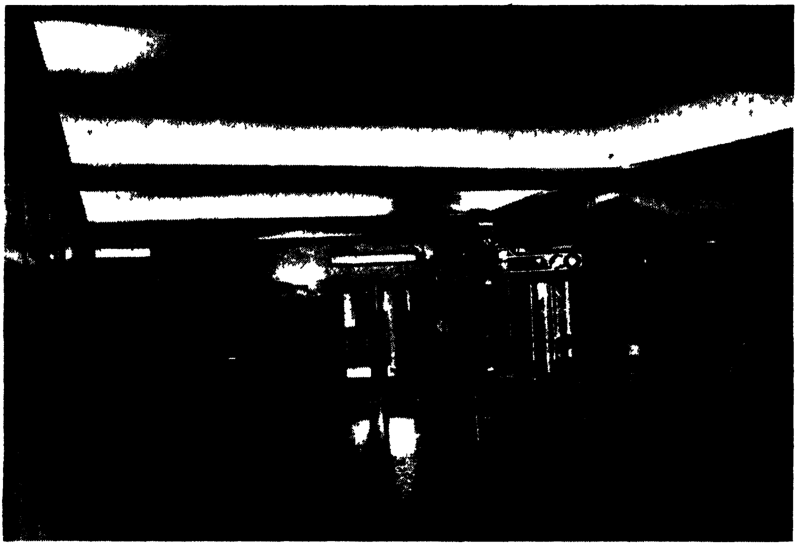
Chapter 11

HIGH VOLTAGE (COLD CATHODE) FLUORESCENT LIGHTING

Lamps of the type exemplified by the four or five feet long fluorescent tube from one to one-and-a-half inches diameter, operated at or less than mains supply voltages, are known as "Hot Cathode" lamps. The fluorescent light source with which we are here concerned, the so-called "Cold Cathode" tubing, is very much similar to the luminous tubing employed in Neon Signs.

There are points in favour of each of these types of fluorescent lighting. Hot-cathode lamps operate at lower voltages, but require heaters controlled by automatic starting switches to strike the discharge. In addition, they need to be connected in series with a choke.

On the other hand, cold-cathode fluorescent tubing of reason-

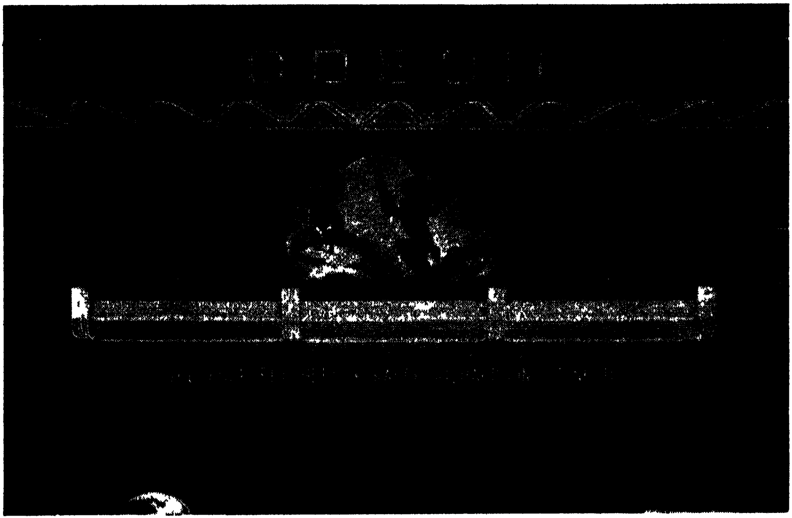


(*Miller Electric Co. Ltd*)

Fig. 79.—Concealed H.V. Fluorescent Lighting Installation at Mayfair Cinema, Aigburth, Liverpool

able length and stability, whilst not needing auxiliary starting gear, must in most cases be operated from step-up transformers. It has the advantages over the hot-cathode type of being more flexible and having longer life, and is thus better suited to decorative lighting schemes.

A cold-cathode tube consists essentially of a glass tube, either clear, coloured or coated with fluorescent material, fitted with an electrode at each end, exhausted and filled with rare gas at low pressure (in most cases with a small quantity of mercury added).



(B.T.H.)

FIG. 80.—EXTERIOR H.V. FLUORESCENT INSTALLATION

The standard 80-watt fluorescent lamp is provided with electrodes (or cathodes) which emit electrons thermionically. Heaters are used in starting the discharge and the electrodes operate at a temperature of about 900° C. In contrast, the cold-cathode tube is fitted with plain cylindrical or cup-shaped electrodes which depend on ionic bombardment for electron emission, and which operate at much lower temperatures (about 150° C. as a general rule).

Hence, a cold-cathode tube may be defined as a luminous discharge tube in which the cathodes are operated at approximately the same temperature as that of the arc stream or luminous column.

Fluorescent Substances

As in the case of the hot-cathode fluorescent lamp the efficiency of the cold-cathode tubes is greatly increased by internally coating them with phospors that respond to a wavelength of 2537Å, and which emit in the visible range. Furthermore, the range of available colours is considerably extended and the beautiful pastel colours suitable for interior decorative lighting are obtained.

In the early days of neon signs, the fluorescent effect was used in canary glass for green tubes. This glass contained salts of uranium, the radio active metal, and was presumably the first attempt to employ fluorescence in luminous tubes.

Radio activity has really been the means of demonstrating the present-day theory of the atom. This has been borne out by the recent investigations resulting in the invention of the atomic bomb. Some years ago the electrically-charged atom of helium, the alpha ray, was detected by its action on a fluorescent screen, and the property possessed by some substances of ionising a gas was discovered.

Many substances in solid, liquid and gaseous forms, have the property of absorbing electro-magnetic energy of certain wavelengths. In general, these effects are referred to as "Luminescence". An early example of this is the phosphorescent afterglow obtained from luminous paint that has been previously exposed to visible light or ultra-violet radiation. But in the case of "Fluorescence", the particular phenomenon with which we are here concerned, there is relatively little afterglow; the visible emission ceases almost immediately the exciting radiation is stopped.

High-voltage low-pressure discharge tubes of the argon-mercury-vapour type, as used extensively for signs, are rich in ultra-violet radiation, which, by its action on fluorescent powders, can be converted into visible light.

Some years ago it was discovered that coatings of zinc sulphide and willemite (made luminescent by the addition of traces of heavy metals) when applied to the interior walls of cold-cathode argon-mercury-vapour discharge tubing were converted into tiny crystals, each a light source in itself, by irradiation with ultra-violet of suitably long wavelength. These powders enabled the range of available colours to be extended but contributed little to the efficiency of the tubing as a source of light.

The introduction shortly before the World War II of zinc beryllium silicate which, when excited by low pressure mercury discharges, fluoresces with high efficiency of light output, was a definite milestone in fluorescent tube development. This substance could be prepared to give various colours of fluorescence. Calcium tungstate and zinc silicate were also employed at this time.

Other fluorescent substances later introduced were magnesium tungstate and chlorophosphate and borate of cadium.

Cold-Cathode Tubing

In the standard 5 feet long 80-watt fluorescent lamp, the cathodes or electrodes are preheated. An auxiliary circuit containing filaments is used for starting in conjunction with a thermal switch for cutting out the filaments after the discharge has been struck. The function of the cathode is to introduce electrons into the tube which contains a small quantity of rare gas and mercury vapour at low pressure. Due to the liberation of electrons into the rarified gas and mercury vapour, a certain amount of both visible blue light and invisible ultra-violet radiation is produced. The ultra-violet constitutes about 80% of the energy of the discharge in a fluorescent tube.

In the cold-cathode tube there is no pre-heating. The supply of free electrons is provided by internal bombardment of the cathodes set up by the voltage applied across the tube.

Recent Developments

Until fairly recently, the development of cold-cathode tubes for illumination was hampered by the necessity for very high voltage operation since the cathode drop was of the order of 150 volts per pair in comparison with about 16 volts in fluorescent lamps; open circuit voltages of over 200 per foot of tubing were commonly employed for cold-cathode fluorescent tubes of 20 millimetres diameter.

However, a type of cold-cathode tube recently introduced operates on 430–460 volts, and requires a striking voltage of only 720. It has an initial efficiency of 40·3 lumens per watt, including ballast, and has a rated life of 8,000 hours. Its three standard colours are white, warm-white and daylight. Starting is instantaneous—no switch or starting device is necessary. The initial efficiency may only be slightly higher than that of fluorescent lamps, but depreciation throughout life is considerably less.

Under normal conditions, the surface brilliancy of cold-cathode tubes is 1,540 foot lamberts.

Connection

These tubes can be connected in pairs in a similar manner to that employed for hot-cathode fluorescent lamps. Thus, there will in this case be a difference in brightness between capacity lamp and inductance lamp if the voltage falls very low. By means of this dual circuit or twin tube arrangement, stroboscopic effect is almost entirely eliminated. Voltage variations of from 95% to 125% will not cause lamp failure or flicker, but will affect light output.

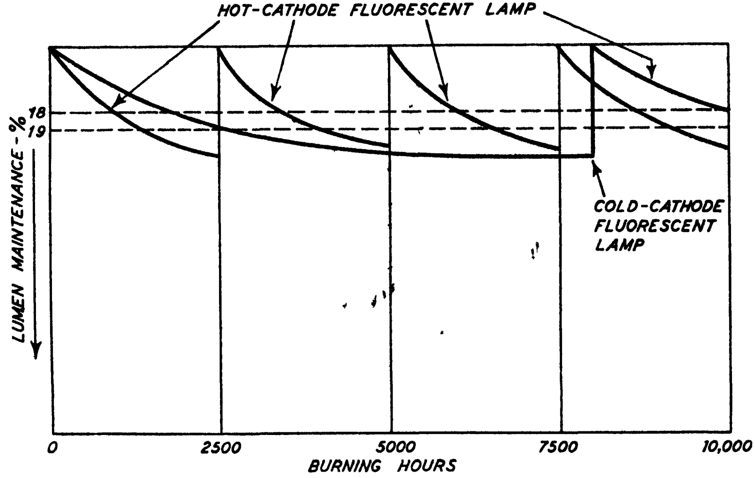


FIG. 81.—LAMP DEPRECIATION

Within reasonable limits, rise in ambient temperature does not decrease the efficiency of the tubes, which will operate efficiently in temperatures as high as 120° F. In a circuit of two lamps, the temperature rise in the ballast is negligible when one is out of service.

Life

The life of hot-cathode fluorescent lamps is usually determined by exhaustion of the heated electrode emission coatings. In a well designed cold-cathode tube, the emission coatings are not heated to any appreciable extent, and the useful life is not necessarily dependent on the dispersal of the emission material.

Much of the high loss in light output during the first 150 hours

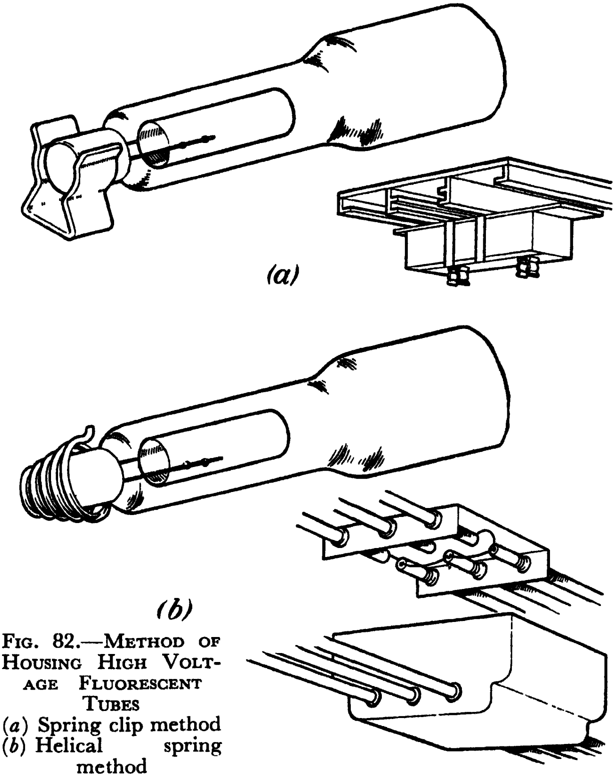


Fig. 82.—Method of Housing High Voltage Fluorescent Tubes
(*a*) Spring clip method
(*b*) Helical spring method

of life of the mains-voltage fluorescent tubes is mainly caused by the action on them of ionised mercury vapour. As the number of ions that come in contact with the fluorescent powder is dependent on the current density of the tube, it is obvious that this is vitally important in maintaining the light output. Cold-cathode tubes, of course, operate at considerably lower current densities than hot-cathode fluorescent lamps.

Installation Costs

Installation costs of cold-cathode lighting, although slightly higher, compare very favourably with those of other tube light sources. There is a method of arranging multiple cold-cathode tube installations with four-gang housings; a disconnection jack prevents removal of any lamp without first switching off. The tubes float between helical springs, and are removed by pushing towards the far end and releasing at the near end.

Cold-cathode tubes are a most adaptable source, since they can easily be manufactured in curves and shapes to suit special cases, and may be dimmed by choke control.

Technical Data

Technical data relating to two "Colovolt" cold-cathode tubes (General Luminescent Corporation, Chicago, U.S.A.) operated on one Duo Ballast is tabulated below:

Total lumen output	2,200
Average tube life	10,000 hours
Lumens per watt of tube	52·4
Lumens per watt including reactor loss	41·5
Overall power factor	99%
Primary wattage	109
Amps—capacity tube	0·118
Amps—inductive	0·122
Surface brightness of tube	3·4 c.p./sq. in.

For the long continuous lines of tubing often required in interior lighting installations, two types of housing are available; an end assembly and an intermediate assembly. Named by the manufacturers "Simplicity" assemblies, these are finished in flat white paint and are supplied completely wired with ballasts. The bottom covers are removable for replacement of tubes.

Pictorial Display Lighting

Cold-cathode fluorescent discharge tubing forms an excellent medium for luminous pictorial display lighting of hotels, restaurants, cinema and theatre foyers, etc. When used as a subsidiary lighting to the general lighting scheme (preferably concealed fluorescent lighting), very attractive effects can be obtained, which can be designed to harmonise with the interior decoration. Cold-cathode tubing is chosen on account of its flexibility; being of reasonably small diameter, it can easily be fashioned into any desired outline.

The most obvious form of decorative lighting display is the luminous frieze. This consists essentially of cold-cathode tubing mounted direct to some fire-resisting wall board or panelling, with provision left at the back for housing auxiliary gear and connections. Some ready means of access for maintenance purposes must, of course, be allowed for. Since rather high voltages are used to operate this type of tubing, special precautions must be taken in the wiring and installation, and in most cases, the sanction of the local fire salvage department must be obtained in addition to that of other interested authorities. The electrodes may be arranged to pass through the panel and high tension connections are thus concealed. Each transformer is connected to a separate primary sub-circuit, and the whole installation is controlled by a double-pole ironclad locking switch.

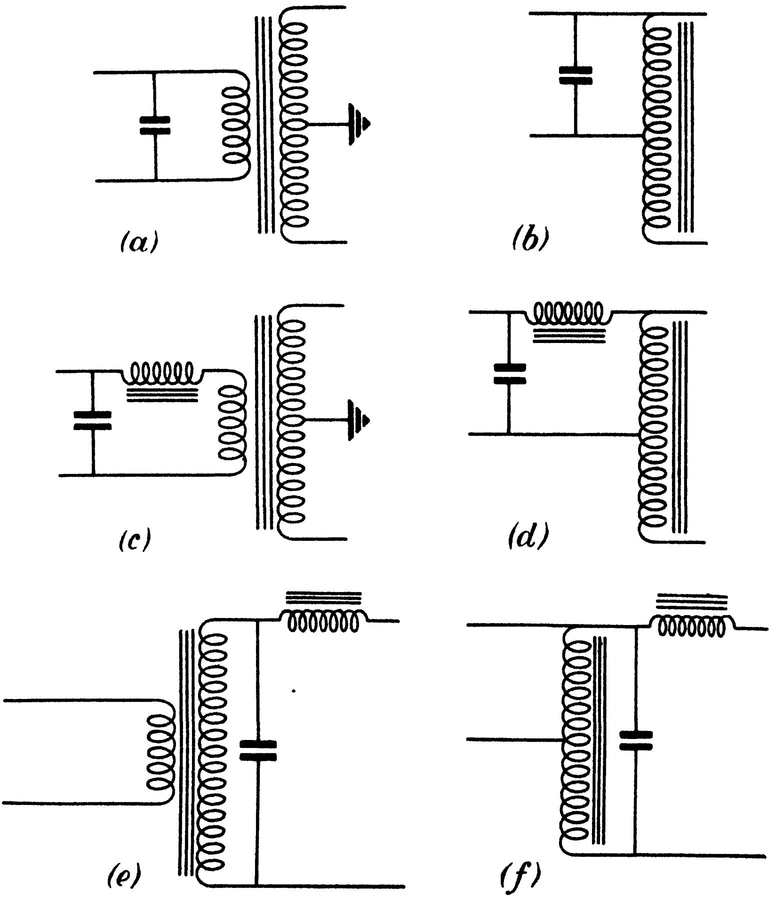


Fig. 83.—Transformer Connections

(*a*) Double wound reactive; (*b*) auto reactive; (*c*) double wound, choke in primary; (*d*) auto, choke in primary; (*e*) double wound, choke in secondary; (*f*) auto, choke in secondary.

In concert halls and ballrooms luminous tube frieze lighting could be controlled and dimmed to suit particular requirements. If the reds, blues, and greens were separately connected, the colour of the resultant light output could be varied in accordance with any prearranged schemes. For instance, where the impression of warmth is to be conveyed red should predominate, whilst a cool atmosphere is created by bluish-white light.

By aid of the microphone in conjunction with thyratron reactor control, the frieze lighting may be varied accordingly to the frequency of the sound emitted. Thus, an appropriate colour light atmosphere can be created in sympathy with the orchestral music.

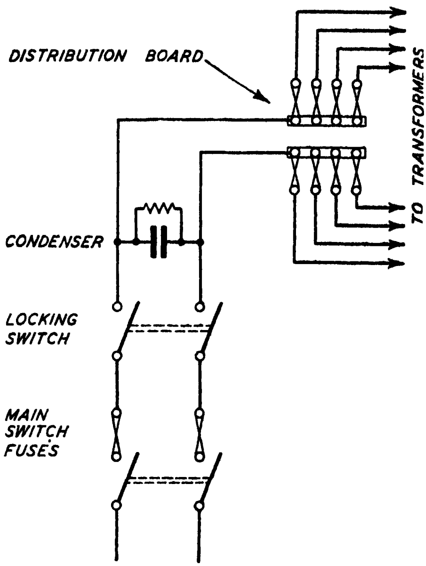


Fig. 84.—Low Tension Circuit

CIRCUITS

Secondary Circuit

The minimum secondary voltage required for a cold-cathode fluorescent lighting unit must not, of course, be less than the striking voltage of the tube sections used. From the point of view of public safety it is not advisable to employ more than 5,000 volts above or below earth potential. Due to the negative characteristic of the tubes, after the discharge has been struck the voltage will drop with increasing current. Obviously, therefore, a certain amount of reactance must be included in the circuit to limit the current. This is provided either by chokes or by utilising leakage reactance transformers.

In the case of the leakage reactance transformer, the primary coil itself acts as a choke under "no load" conditions by carrying a wattless current. Full output voltage is thus obtainable on first switching on, enabling the discharge to strike. But as soon as the tube lights up, the magnetic leakage comes into operation, causing a drop in secondary voltage. Many cold-cathode fluorescent tube transformers are provided with adjustable magnetic shunts in the iron cores.

By splitting the secondary coil of this type of transformer (i.e. earthing the centre-point) the maximum potential above earth may be halved.

Low Tension Circuit

The low tension circuit of a cold-cathode fluorescent tubing installation comprises main switch and fuses, power factor correction condenser, locking-switch, distribution board, the wiring connecting this apparatus to the consumer's terminals and, also, the final sub-circuits feeding the transformer primaries.

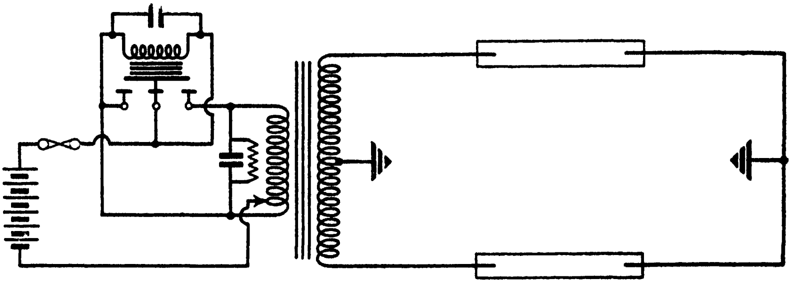


Fig. 85.—Battery Operation Circuit

There is a section (No. 8) of the I.E.E. Regulations for the Electrical Equipment of Buildings which deals with luminous tube installations. In addition, many local authorities have their own rules in this connection. It will be seen from Fig. 84 that a locking-switch must be included; this usually takes the form of a double pole ironclad switch with a detachable handle. If, for maintenance purposes or for any other reason, it is necessary for work to be done on the luminous tube installation, the workman removes the handle, keeping it in his possession until the job is completed, thereby preventing the possibility of the tubing being inadvertently switched on.

If a rotary convertor is installed, the D.C. supply circuit, starter and other apparatus must conform to the appropriate regulations.

Simple Series Circuit

Unlike hot-cathode fluorescent tubes (typified by the standard 80-watt 5 feet long lamp), cold-cathode tubing strikes up immediately the primary control switch is made; no starting switch is necessary in the circuit. A disadvantage of the simple series circuit shown in the diagram is that in the event of one failing, both tubes will be extinguished and the maintenance electrician would not know immediately which of them was faulty.

This disadvantage may be offset by means of the—

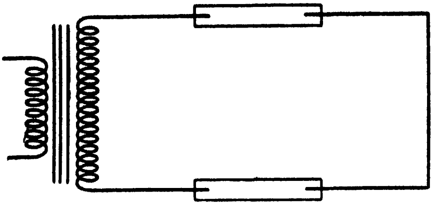


Fig. 86.—Simple Series Circuit

Earthed Mid-point Circuit

In this, the centre of the luminous tube circuit is connected to earth, so that half of the tubing comprising the secondary load will continue to function in the event of a failure.

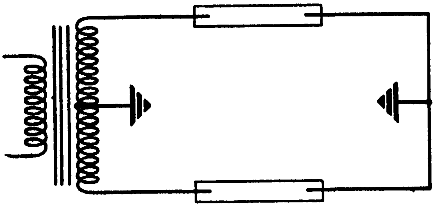
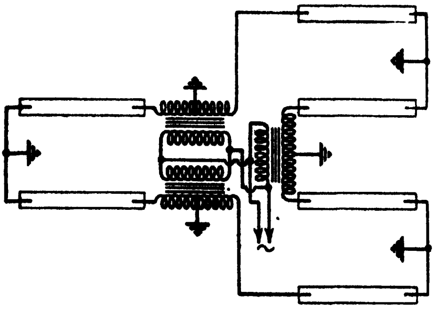


Fig. 87.—Earthed Mid-point Circuit

Multi-Transformer Circuits

May be used for cove lighting or borders of cold-cathode fluorescent tubing, provided that the aggregate input loading of the transformers on any primary final sub-circuit does not exceed 1,000 volt-amperes.

The primaries must, of course, be arranged so that the secondaries will be additive.



(By courtesy of the "Electrical Times.")

Fig. 88.—Multi-Transformer Circuit

Inductance-Capacitance Circuits

A cold-cathode tube in which the electrodes are designed to be self-heating during discharge may be arranged in series with a choke and condenser, with an additional choke connected across the lamp.

On switching on, the circuit is in a condition of partial resonance, which gives rise to increased voltage across the tube electrodes. Once the discharge has struck, the choke connected in parallel is practically short-circuited due to the low impedance of the tube. The tube then continues to operate with what is substantially a series ballast, and, since the reactance of the condenser is considerably greater than that of the series choke, draws a leading current from the supply. (Fig. 89a).

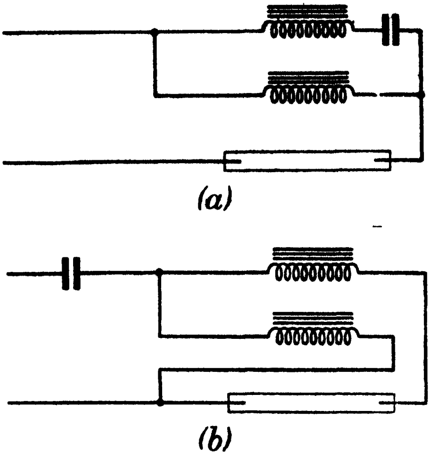
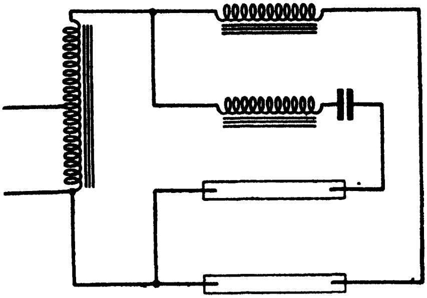


Fig. 89.—Inductance-Capacitance Circuit (Brit. Pat. 527,497)
(*a*) Choke across tube.
(*b*) Choke across tube and choke

An alternative method of connection is shown in Fig. 89b, in which one choke is arranged to shunt both the tube and the other choke.

In this case, after switching on and partial resonance, the shunting reactor has the effect of absorbing and smoothing out high current peaks produced by the reactor that might damage the tube electrodes.



(By Courtesy of the "Electrical Times").

Fig. 90.—Twin Tube Constant Current Circuit

These methods of connection are the subject of British Patent No. 527,497.

Twin Tube Constant Current Circuit

Cold-cathode fluorescent tubes may be connected in a twin tube circuit in much the same way as hot-cathode tubes.

In the "constant current" circuit each tube is controlled by a series inductance and capacitance. Transformers used in this way must be carefully designed to minimise hum from vibrating core laminations; this vibration may be obviated by utilising very accurately die-cut laminations assembled by a special "pressing-in" operation.

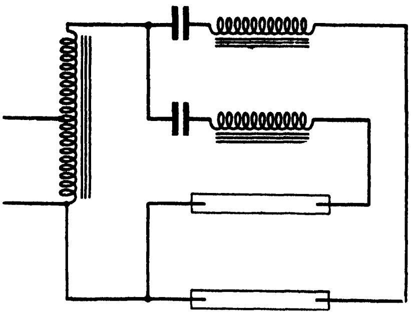
The drop off in light as the current passes through zero gives rise to a certain amount of stroboscopic effect, but the time element should be small, and the cyclic variation in most cases would not be harmful or annoying provided that the wave shape was good.

The light output from tubes operated with this circuit remains reasonably constant with small changes in primary input voltage, since the core flux densities are high.

Twin Tube Inductance Capacitance Circuit

If one tube is controlled by an inductance and the other tube by an inductance and capacitance in series, stroboscopic effect is minimised and the overall line power factor is considerably improved.

In this case, however, a decrease in line voltage may result in a difference in tube current and, hence, lumen output.



(By courtesy of the "Electrical Times")

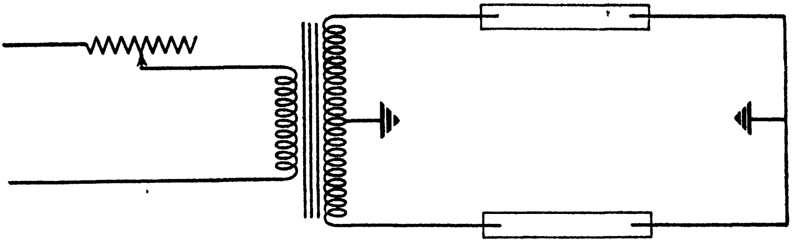
FIG. 91.—TWIN TUBE INDUCTANCE CAPACITANCE CIRCUIT

DIMMING

High voltage cold-cathode tubing cannot be dimmed to extinction owing to flicker at low current values. As a general rule, argon-mercury vapour tubes may be effectively dimmed to about 10% of their maximum light output, whilst neon-filled tubing can only be reduced satisfactorily to something like 15%.

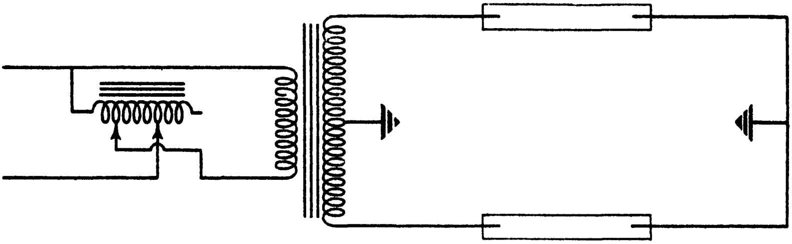
Resistance Dimming Control

A variable series resistance in the primary circuit, although wasteful, is suitable for dimming small fluorescent tube installations. It is wasteful, of course, because the wattage consumption remains practically constant—even when the illumination given by the tubes is a minimum. When this minimum illumination condition is reached, most of the energy is dissipated by the resistance, which must therefore be adequately protected and ventilated.



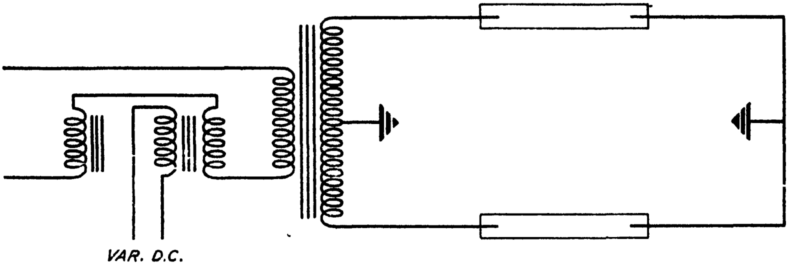
(*By courtesy of the "Electrical Review"*)

FIG. 92.—RESISTANCE DIMMING CONTROL



(*By courtesy of the "Electrical Review"*)

FIG. 93.—VARIABLE VOLTAGE TRANSFORMER DIMMING CONTROL



(*By courtesy of the "Electrical Review"*)

FIG. 94.—SATURABLE REACTOR DIMMING CONTROL

Variable Transformer Control

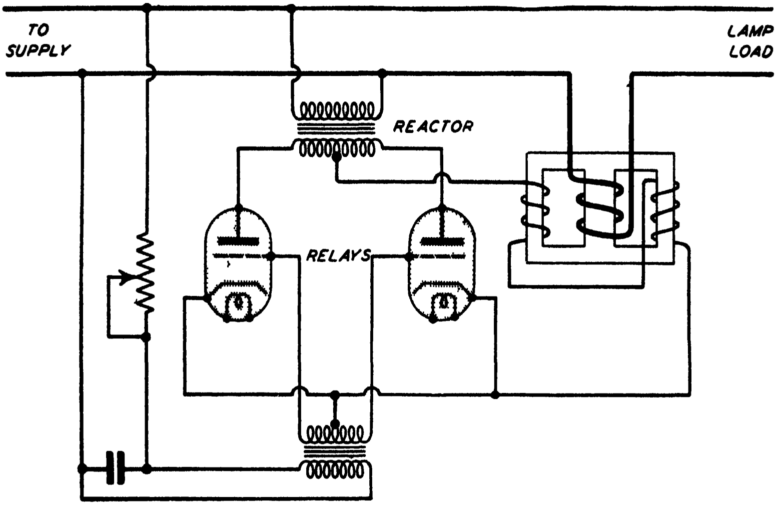
Continuous control of the fluorescent lighting over a wide range can be obtained by using a variable voltage auto-transformer. In this case the wattage consumption is dependent on the light output. Little energy is absorbed by the transformer itself.

When the cold-cathode tubes are hardening, or nearing the end of their efficient life, the auto-transformer provides a ready means of stepping up the voltage. Thus, the light output can be maintained reasonably constant throughout the life of the tubes.

Saturable Reactor Control

In this circuit, a saturable reactor has three coils, two of which are interconnected and joined up in series with the transformer input. The third or centre coil is supplied from a source of variable direct current.

A small D.C. through the centre coil produces magnetic saturation of the core, so that the effective inductance of the reactor is reduced, thereby increasing the current through the fluorescent tubes.



(*By courtesy of the "Electrical Review"*)

FIG. 95.—THYRATRON CONTROL

Thyratron Control

Thyratrons have been used widely in the U.S.A. for dimming. This form of control is more efficient than the variable rheostat method and it can be supplied to a large number of cold-cathode fluorescent tube circuits.

The principle used is that of supplying the luminous tube load through a saturable core reactor, the saturation being provided by the rectified output of two grid-controlled gas-filled relays. Thus, under conditions of core saturation, little impedance is offered by the reactor, whilst if the rectified current is switched off, the appreciable impedance of the reactor causes the lighting load to be dimmed. A potentiometer rheostat is transformer-connected to the grids of the thyratrons.

The type of saturable reactor used consists of a laminated iron core on which two windings are fitted. One winding, in series with the lighting load, is connected to the A.C. supply; the other supplied from the thyratron, carries D.C. Thus, when the fluorescent tubes are completely dimmed and no D.C. saturating current is flowing, considerable impedance will be offered by the A.C. winding.

For particularly complex theatre lighting control, utilising pre-set features, individual potentiometers are set to give the required lamp brightness for each scene, and a high-resistance "scene-changing" potentiometer is necessary for fading each scene into the next. Total "black-out" control is provided for by a master potentiometer.

An interesting example of thyratron reactor control was installed just prior to the outbreak of war in the ballroom of R.M.S. *Queen Mary.*

In this case the equipment was arranged for sound control and the lighting was split up into three banks of red, blue and green. By the aid of a microphone in conjunction with the thyratron reactor circuit the lighting could be varied according to the characteristics of the orchestral music. A great variety of tints could be obtained in this way, and the amplitude of the sound emitted determined the density of illumination provided; the light altering automatically in sympathy with the music.

OPERATION

The satisfactory operation of luminous tubing depends to a large extent on careful processing and installing and correct selection of transformers. Some of the more important factors affecting the performance of luminous tubes, and particularly their life, are discussed in this chapter from a manufacturing point of view.

Variation of Voltage Drop with Tube Pressure

Incorrect gas pressure affects both the electrical resistance and the life of luminous tubing. Insufficient pressure means a scarcity of atoms, resulting in less opportunity for collision between atoms and electrons—in other words reduced possibility of ionisation—and consequently higher resistance. Since the gas will also be cleaned up more quickly than if the tube were filled at correct pressure, the life will be shorter. On the other hand, too great a pressure would give slightly longer life and possibly greater resistance, because in this case there will be too many atoms in the path of the electron stream, thus reducing electron speed to a point where it will be impossible to knock more electrons off atoms, resulting, again, in reduced ionisation. The gain in life would not be proportional, as more current would be required, nor would such tubes be as efficient as a normal one.

It would at first appear that the optimum point of a curve in which tube pressure is plotted against electrical resistance would be the value to use. This, however, is not the case, since clean-up or sputter by the electrodes will reduce the pressure during operation of a tube. In effect, a decrease in pressure has much greater effect on the electrical resistance than an equal increase. Thus, the normal gas pressure at which tubes should be filled is always slightly higher than the optimum point, being generally 15 to 20% above this when using untreated electrodes. For oxide-coated electrodes, about 5% above the optimum point is used, as the gas is not cleaned up so rapidly as with uncoated electrodes.

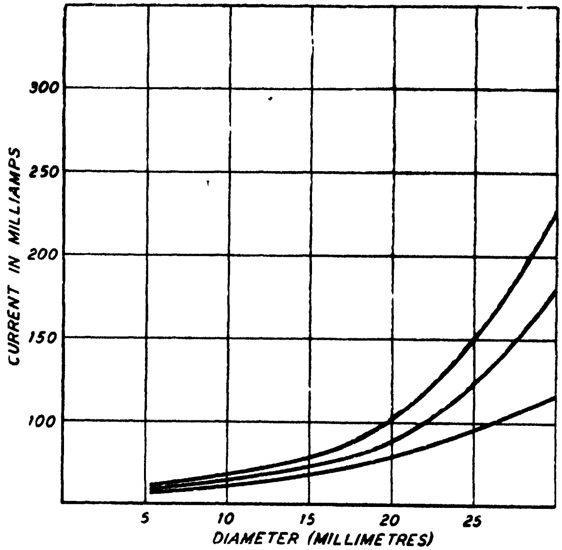


FIG. 96.—VARIATION OF CURRENT WITH TUBE DIAMETER

Tube Diameter versus Voltage and Current

As a general rule, the voltage necessary to operate a given size tubing is proportional to the tubing length. The current flowing through the tube determines the brilliancy. As a practical example, compare two 10,000-volt transformers, one providing 30 milliamperes, and one 60 milliamperes. Both would, theoretically, operate the same length of a given size of tubing, but the tubing would be brighter when operated at 60 milliamperes.

However, the resistance of small diameter tubing is greater than that of a large diameter tube, hence higher voltage is necessary for those of smaller diameter. In addition, a greater striking voltage in proportion to the operating voltage is necessary for small diameter tubing.

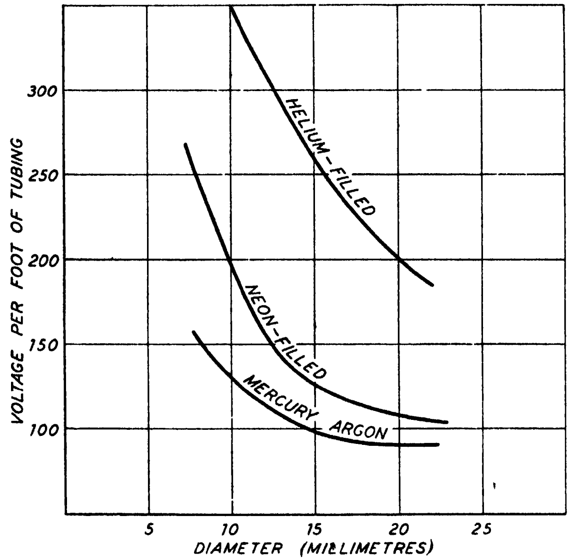


Fig. 97.—Average Voltage per foot Required for Tubing of Different Diameters

Since the current density varies as the area of the tubing, the brilliancy of a tube is dependent on the diameter. For instance, a 10 millimetre diameter tube would have a cross-sectional area of 78·5 square millimetres and a 15 millimetre diameter tube 176 square millimetres. If the 10 millimetre tube is operated at 15 milliamperes, it will be necessary for about 34 milliamperes to pass through the 15 millimetre tube in order to provide the same degree of brilliancy.

Electrode Drop

The electrode plays an important part in luminous discharge tubes, since it may be regarded as the link between the electric supply and the gaseous conductor.

Electrode "drop" refers to the voltage drop that takes place between the electrode and the ionised gas. The amount of this drop varies greatly and depends upon the size and shape of the electrode, the materials of which it is constructed and its treatment.

The electrode drop on a very large diameter tube is frequently visible to the naked eye, appearing as a dark—or non-luminous—space within the tube; its presence is due to the fact that the gas at this spot is not being sufficiently ionised. This may be explained by the fact that there is a strong electrical field at such points, thus the electrons cannot reach sufficient velocity to cause ionisation.

When the electrode is coated with an alkaline earth metal (such as calcium, barium, strontium, or caesium) the electrode drop appears to be lower, the general theory being that the electrical surface tension is thereby reduced, making it easier for the electrons to be ejected. Alkali metal coatings, generally speaking, have the effect of reducing sputtering, but increase the time necessary for processing and have an affinity for mercury.

Sputtering

During the life of luminous discharge tubes, the gas pressure is gradually decreasing—very slowly at first and more rapidly towards the end. This is due to sputtering; that is, the process during which minute particles of metal are detached from the electrodes by electronic impact. The free electrons, moving at terrific speed, knock off the particles which then attach themselves, ideally to another part of the electrode, but, more often, to the adjacent interior of the glass envelope. In this transfer of metal particles, small quantities of rare gas are trapped, thus causing the pressure to drop and the electrical resistance to increase. The rate of sputter is, of course, dependent on the original gas pressure and the voltage and current at which a tube is operated.

Each metal has a definite rate of sputter, pure iron having the lowest (about 4), although copper, with a sputter factor of 180, is claimed by some manufacturers to be far superior to iron when chemically coated and used in fluorescent tubes. Owing to its relatively fine grain and non-porous structure, iron is difficult to treat chemically, but the spongy crystal structure of copper lends itself admirably to this purpose. It would appear that there is much scope for research in the chemical treatment of iron electrodes, for the coatings tried so far have been found to flake off very easily. Up to the time of writing, no satisfactory electrode coating has been developed for use in cold-cathode tubes containing mercury, which attacks the alkali earth metals.

Swedish iron (more frequently known as "Svea" metal) is undoubtedly the best material for use in cold-cathode luminous tubes. The pertruded cylindrical type pre-heated in hydrogen still appears to be the last word in uncoated electrodes; although for certain colours of luminous tubing (notably white and gold) the application of a barium-strontium salt by means of a butyl acetate binder gives better results for a period.

Hardening

Sputtering is undoubtedly the deciding factor in the life of a normal luminous tube. When the internal gas pressure has decreased to such an extent that the discharge can no longer be maintained, the tube is said to be "hardened". This process can be better appreciated if we reconsider what is going on during operation of the luminous tube.

Due to the application of a high voltage alternating current, there is a continual motion of ions and electrons. The positive ions, approaching the cathode, are accelerated to such an extent that they knock off minute particles of metal. Thus, the period that elapses before hardening takes place depends on the number of ions and electrons present, the force of impact, and the properties of the electrodes: in other words, the gas pressure, the current, and sputter factor and porosity of the metal of which the electrode is made. Slight impurities present in the tube do not appreciably affect its life unless they react with the electrodes.

A high gas pressure does not necessarily mean that there will be more ions, as the gas may not be fully ionised. On the other hand, although reduction in pressure may result in fewer ions, the mean free path will be longer in this case, and the force of impingement at the cathode (m.v) will be greater.

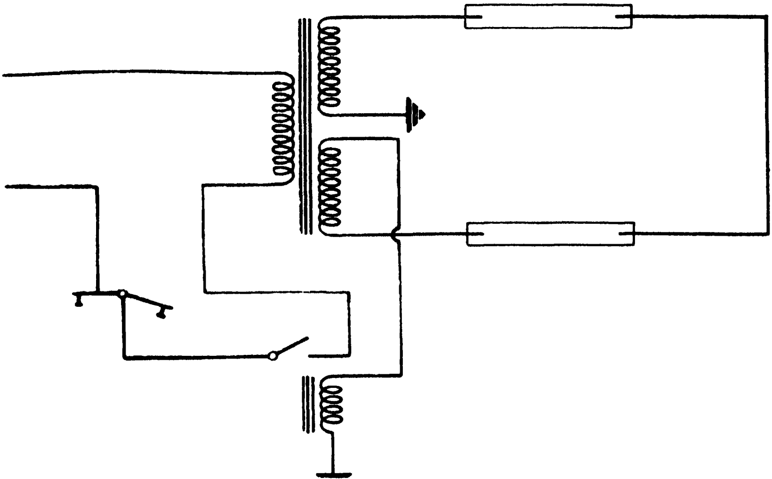
When the current is passing from metal to gas (at the electrode), a certain amount of heat is produced which, if excessive, will increase sputtering and accelerate the hardening, This is mainly a question of the cathode drop of the electrode metal. Swedish iron electrodes of correct design operate at a temperature of about 150° C., which does not seriously affect sputtering.

The absorbtion of rare gas by the electrodes themselves is usually negligible, since the metal is already saturated at the outset.

In general, a life of something like 5,000 hours may be expected from tubes filled at a pressure of 5 to 8 millimetres, fitted with Svea electrodes not less than 0·1 mm. thick, and operated at current densities of from 10 to 15 milliamperes per square inch.

SAFETY DEVICES

The most obvious form of protection against high voltage shock from cold-cathode luminous tube circuits consists of making access to the connection impossible without first breaking the primary circuit.



(*By courtesy of the "Electrical Times"*).

Fig. 98.—Neontrip Safety Device

If, for instance, the transformer and high tension wiring is housed in a metal case provided with a removable cover, it is a comparatively simple matter to arrange that the low tension circuit is automatically disconnected whenever the cover is removed.

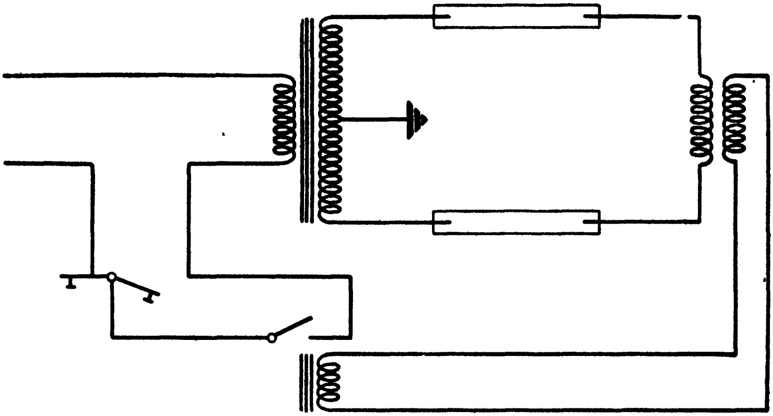
Neontrip Safety Device

A protective device, known as "Neontrip", which automatically interrupts the main supply to the transformer primary in the event of an open circuit or earth fault, is described in British Patent Specification No. 496,083.

Essentially, the arrangement consists of an electro-magnetic relay in series with the tube circuit. In the case of an earth fault the overload of the transformer secondary is made to reduce the voltage below ionisation value of the luminous tubing. Interruption of the current due to a break in the circuit provides open-circuit protection.

When the centre-point of a transformer secondary is earthed two differential relays are used—one to protect each half of the circuit. Development of a fault then causes a movement of either relay armatures which, in turn, operates a switch included in the primary supply.

As the electro-magnets (supplied either direct from the secondary windings or through condensers) are provided with an additional winding derived from or linked with the primary, it can be seen that an open circuit will result in zero current through two electro-magnet windings, thus causing the energised windings to pull the armatures over and trip the circuit.



(By courtesy of the "Electrical Times")

FIG. 99.—SAFETY DEVICE WITH CURRENT TRANSFORMERS

On the other hand, an earth on one side of the secondary circuit produces an increase of current in that circuit, thereby reducing the secondary terminal voltage as a whole. The remaining half of the secondary will then carry no current and the earthed portion will operate the relay.

Safety Circuit

The next circuit Fig. 99 was developed by the Department of Engineering, Board of Education of Detroit, Michigan, U.S.A., for situations where cold-cathode fluorescent tubes are to be installed within easy reach of the public.

By means of a current transformer, relay and contactor, the primary transformer supply is automatically disconnected in the event of breakage or failure of any of the luminous tubes forming the secondary circuit.

Protective Show Case Device

Another type of protective device utilises a relay in series with the earthed end of the transformer secondary winding. It is used quite a lot in the U.S.A. by manufacturers of refrigerated show cases.

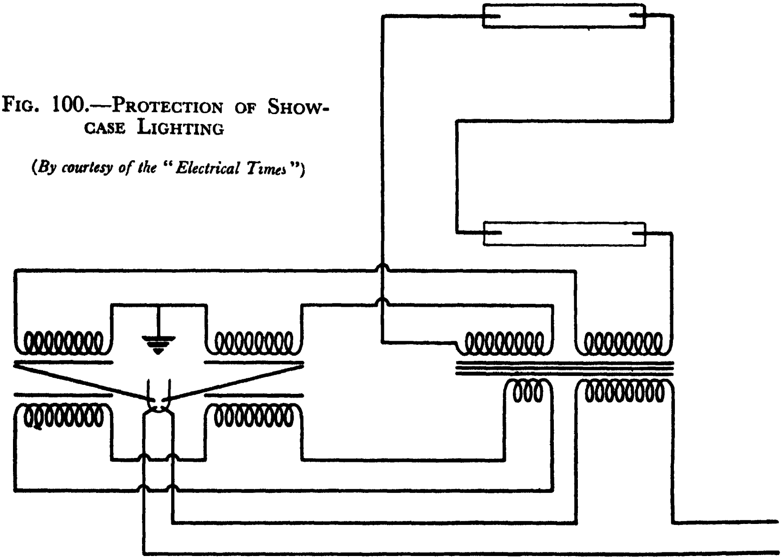


FIG. 100.—PROTECTION OF SHOW-CASE LIGHTING

(*By courtesy of the "Electrical Times"*)

The circuit is operated by closing a momentary contact switch completing the primary circuit. Secondary current then closes the relay contacts and the luminous tubes strike up. Failure of one of the tubes will, of course, render the circuit inoperative, the relay dropping out and switching off the supply to the primary.

If desired, the relay can be designed for low voltage operation.

POWER FACTOR CORRECTION

The type of leakage reactance transformer employed in cold-cathode fluorescent lighting inevitably results in low power

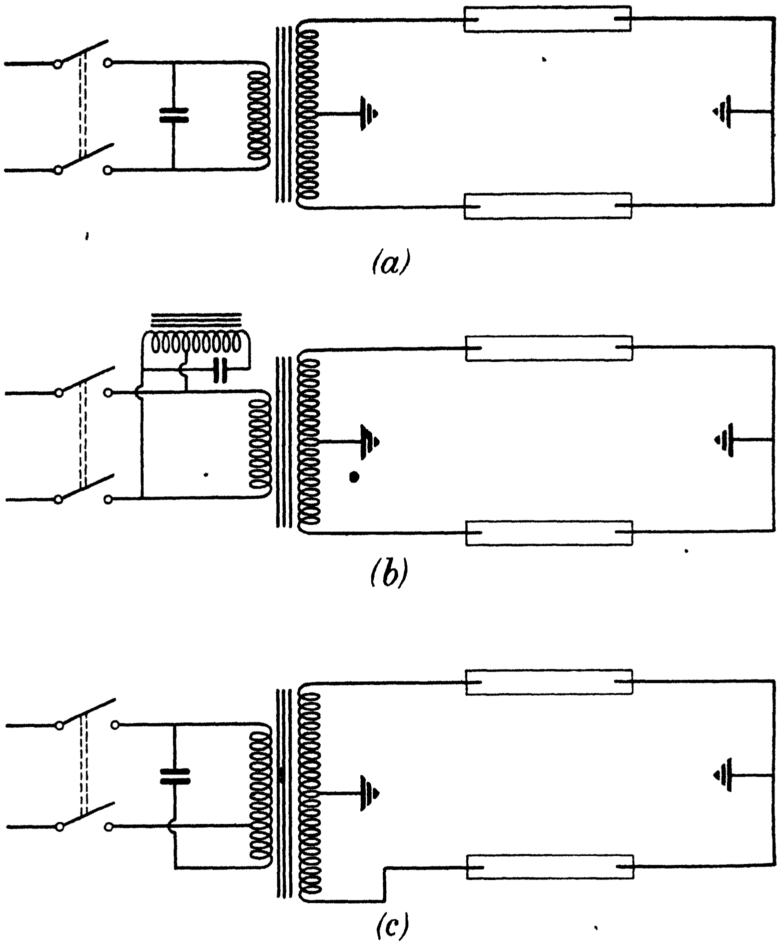


FIG. 101.—POWER FACTOR CORRECTION CIRCUITS
(*a*) Condenser
(*b*) Capacitor transformer
(*c*) High power factor transformer

factor. To comply with supply authorities' requirements, this poor power factor must be improved to at least 0·8.

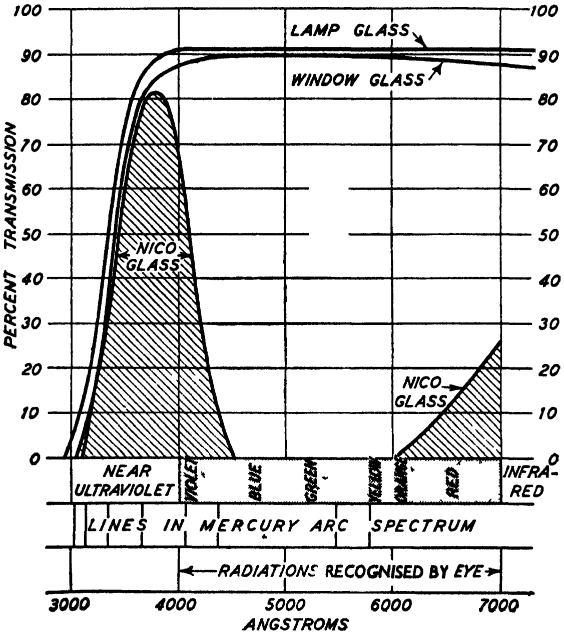
Condensers

The simplest method of correction is to connect condensers of the requisite capacity across the primary supply leads. In accordance with I.E.E. Regulation 812 (F), some means should be provided for the automatic discharge (e.g. by a high resistance leak) on discharge of the supply, of every condenser used.

Capacitor Transformers

A capacitor transformer may be used to reduce the cost of condensers in large installations.

Essentially, this device is an auto-transformer with an extended winding. The effect of the capacitor transformer is obvious when it is considered that if a condenser of 15 microfarads capacity is needed for the correction of a 115 volts luminous tube circuit, only 1 microfarad would be required on 480 volts, which could be delivered to the condenser terminals from the auto-transformer.



(*General Electric Vapour Lamp Co.*)

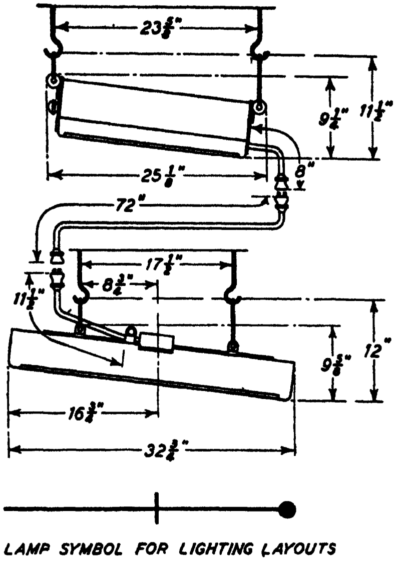
FIG. 102.—TRANSMISSION OF NICO GLASS

High Power Factor Type Transformer

A type of luminous tube transformer known as the "high power factor type", very popular in the U.S.A., has its primary winding extended to a value of about four times the supply voltage in order to reduce the power factor correction condenser capacity.

FLUORESCENT DISPLAYS

In the field of decorative lighting there is a great deal of scope for the so-called "black" or ultra-violet passing tube. The glass used is either Wood's or Nico (Nickel-cobalt) which passes ultra-violet radiation with the minimum of visible light. Usually, a straight tube is housed in a suitable reflector which is arranged to project the radiation on the fluorescent-coated display. Many brilliant and multi-coloured effects can be obtained in this way.



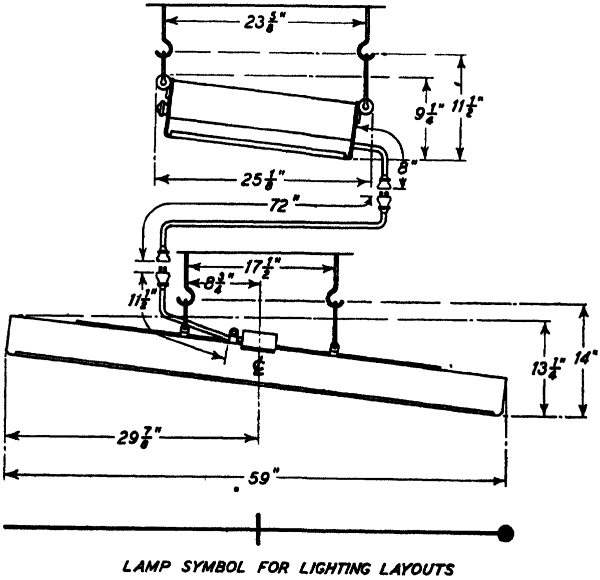


FIG. 103.—DIMENSIONS OF NICO LAMPS FOR FLUORESCING

Fluorescent material can be made up as a paint or a dye, or can be incorporated in some plastic. The range of colours available are shown below.

The tube itself is essentially of the Cooper-Hewitt type. It may be mounted either horizontally or vertically, so that even one or two tubes will give a uniform fluorescent effect over wall panels or displays without obstructing the view of spectators. Under these U.V.—passing tubes, fluorescent paints and dyes have exceptional depth and radiance. If paints are properly applied, there is practically no deterioration in use.

Countless substances have been found to exhibit fluorescence to some degree under the influence of ultra-violet radiation; petroleum jellies and mineral oils particularly.

The effective distances of Nico[1] tubes for good fluorescence together with the areas covered, are shown below:

Range of Colours of Fluorescent Lighting

Paints or Powders

Deep red
Flame
Golden yellow
Sky blue
Red
Salmon pink
Yellow
Royal blue
Orange red
Amber
Lemon
Pale mauve
Orange
Apricot
Apple green
White

Liquids

Red
Rose pink
Yellow
Green
Blue
Orange
Amber
Lemon
Sky blue
Mauve

Plastics

Red
Pink
Amber
Green
Violet
Rose
Orange
Beige
Blue

Chalks or Crayons

Red
Amber
Green
Sky blue
Orange
Yellow
Turquoise
Dark blue

Effective Distances of Nico Tubes and Areas Covered

Distance	*50-inch tube*	*22-inch tube*
Excellent results	3 feet	2 feet
Good ,,	6 ,,	5 ,,
Marginal ,,	12 ,,	10 ,,

---

[1] General Electric Vapour Lamp Co , Hoboken, N.J., U.S.A.

Areas covered	*50-inch tube*	*22-inch tube*
Good results	100 sq. feet	50 sq. feet
Marginal „	400 „ „	200 „ „

The tubes are suitable for operation anywhere within the 86-degree angle bounded by 4 degrees "above" the horizontal and the vertical. Reflectors may be "rotated". Holes are provided in these reflectors for re-locating both the tube clamps and the hanging hooks, making it possible to direct radiation either to the right or to the left. (In the normal position the maximum radiation occurs straight away.) Tube and auxiliary apparatus must not be separated by more than 15 feet.

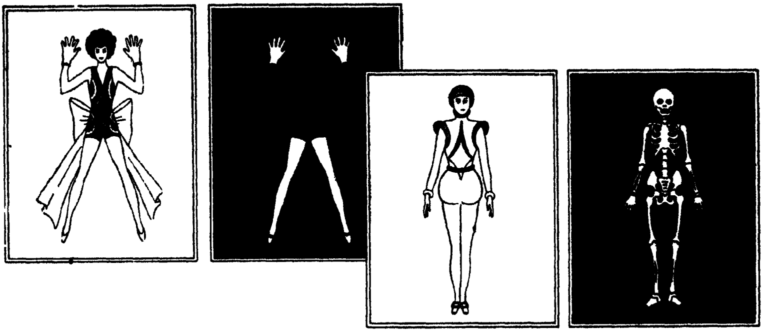


FIG. 104.—THEATRICAL EFFECTS OBTAINED BY USE OF U.V. PASSING TUBE

Specifications for the 50-inch and 22-inch lamps (diameter 1 inch) on 230-volt 50-cycle supplies are:

	50-inch	*22-inch*
Total average watts per tube . .	450	250
Power factor	88%	88%
Average line amperes	2·3	1·3
Weight of unit complete	51 lbs.	48 lbs.

Some very attractive theatrical effects can be obtained from this type of tube by dyeing or painting portions that are required to appear amid darkness so that the normal background disappears.

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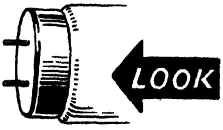

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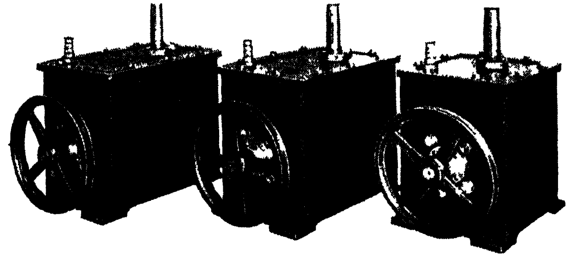

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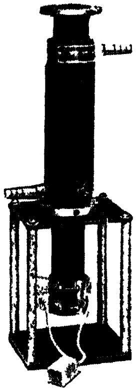

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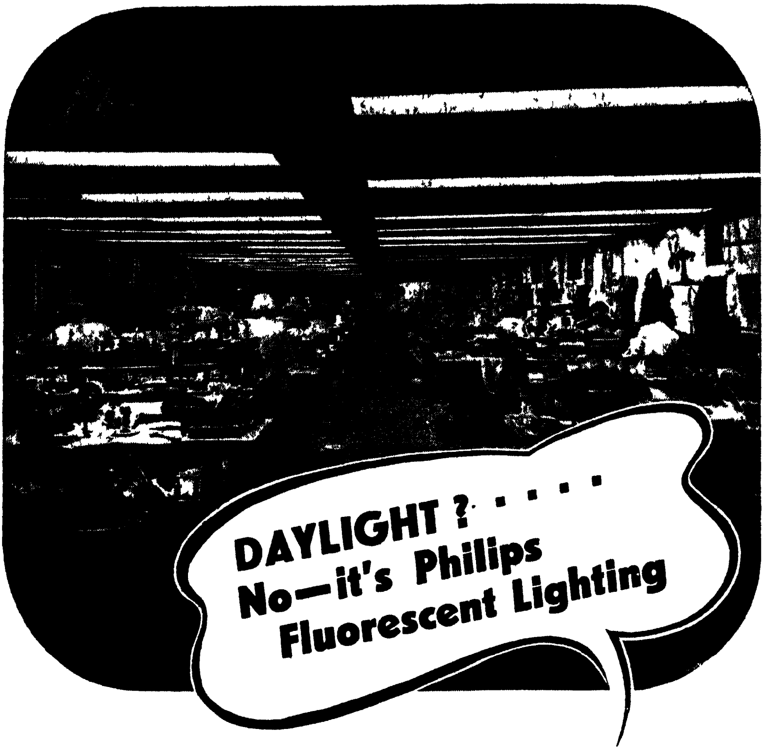

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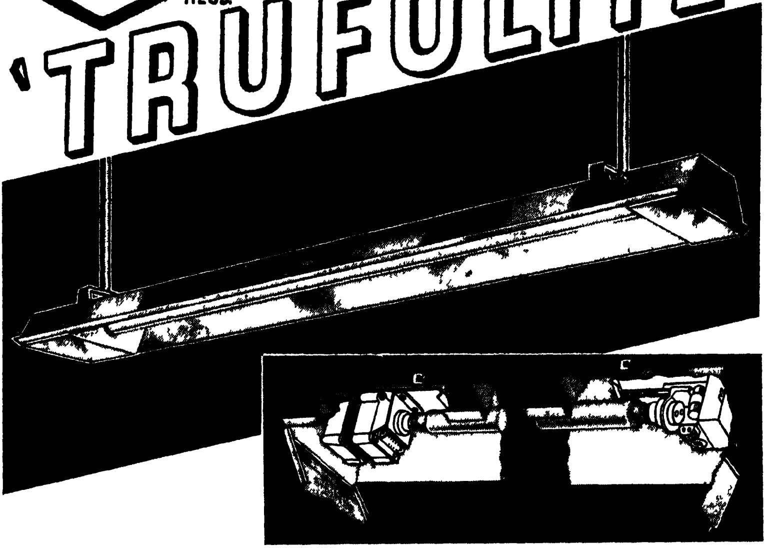

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